DEVELOPMENT OF INTELLIGENT VEHICLE-PEDESTRIAN TRAFFIC CONTROL SYSTEM FOR IMPROVED SAFETY

By

OYENIKE MARY OLANREWAJU

DEPARTMENT OF COMPUTER SCIENCE
AHMADU BELLO UNIVERSITY, ZARIA,
NIGERIA

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Oyenike Mary OLANREWAJU

B. Sc. (Unibadan, 1989), M. Sc. (BUK, 2011) Computer science
(Ph. D./SCI/35487/2012-2013)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DOCTORATE DEGREE IN COMPUTER SCIENCE

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Declaration

I declare that the work in this thesis entitled "*Development of Intelligent Vehicle-Pedestrian Traffic Control System for Improved Safety*" 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.

Olanrewaju Oyenike Mary		31th OCTOBER 2017
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Name of Student	Signature	Date

Certification

This thesis entitled "*Development of Intelligent Vehicle-Pedestrian Traffic Control System for Improved Safety"* by Oyenike Mary OLANREWAJU meets the regulations governing the award of the degree of Doctor of Philosophy in Computer Science of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Prof. A. A. Obiniyi Signature ____________Date__________

Chairman, Supervisory Committee

Prof. O. S. Adewale Signature ____________Date__________

Member, Supervisory Committee

Prof. S. B. Junaidu Signature ____________ Date__________

Member, Supervisory Committee

Prof. S. B. Junaidu Signature ___________Date____________

Head, Computer Science Department

Prof. S. Z. Abubakar Signature ___________Date___________

Dean, School of Postgraduate Studies

Dedication

This thesis is dedicated to Almighty God, The Creator of heaven and earth.

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ABSTRACT

Walking as a mode of transportation has many benefits for pedestrians and the society. Yet, pedestrians are a vulnerable group and safety concerns are a significant barrier to walking especially as vehicle volume increases. Although multiple countermeasures have been proposed to promote pedestrian safety, pedestrian crash rates across the globe indicate that more research is required on pedestrian safety as vehicular volume increases. Transportation Research so far covers congestion reduction, environmental pollution control and signal control system to make vehicular traffic more convenient without adequate consideration for pedestrian right of way. Intelligent transportation research mostly focuses on sensitive system that manages signal timing for vehicular signals. Most research towards pedestrian identify the need for safety by analyzing crash data without proffering adequate solution to vehicle-pedestrian crashes that result from prolonged pedestrian delay. Most transportation and town planners design roadways without sufficient consideration for pedestrians; hence there exist highways with multiple lanes without pedestrian facilities. It is therefore very necessary to have a traffic model that considers pedestrian characteristics as well as vehicle characteristics to harmonize the conflicting interest of waiting pedestrians and driver satisfaction to improve safety. This research work designed an architectural framework that comprises vehicular/pedestrian modules and a reasoner. An intelligent fuzzy logic model was developed to implement the reasoner that harmonizes both vehicle and pedestrian characteristics to dynamically control the signal timing. A four way intersection was modeled in VerkehrInStadten-SIMulationsmodell (VISSIM) traffic simulator to implement the road network. The traffic network was implemented as unsignalized, signalized fixed time traffic control and as Fuzzy Intelligent Traffic Control (FITC). From the evaluation of the system, the FITC achieved average improvement of 53.19% over fixed time traffic control, FITC Pedestrian delay improved by 13.13% over fixed time, hence a potential crash rate reduction from 2.83% to 0.37% using crash data obtained from Federal Road Safety Corps (FRSC) records. Calibration of traffic model volumes also gave acceptable Geoffrey E. Havers (GEH) value of less than 5.0.

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Abbreviations and Acronyms

ADT	Average Daily Traffic
AVENUE	Advanced & Visual Evaluator for road network in urban areas
CBR	Case Based Reasoner
CVIS	Cooperative Vehicle Infrastructure System
DR	Deceleration rate
FITC	Fuzzy Intelligent Traffic Control
FLC	Fuzzy Logic Control
FTTC	Fixed Time Control
GEH	Geoffrey E. Havers
GSM	Global System for Mobile Communication
HAWK	High Intensity Actuated Crosswalk
HCM	Highway Capacity Manual
HVE	High Visibility Enforcement
ITLS	Intelligent Traffic Light System
ITS	Intelligent Transport System
LOS	Level of Service
MATLAB	Matrix laboratory
Max D	Maximum Deceleration
MAXS	Max Speed
NHTSA	National Highway Traffic Safety Administration
OSGI	Open Services Gateway Initiative Framework
PA	Pedestrian Actuated
PELICAN	Pedestrian Light Control
PET	Post Encroachment Time
PUFFIN	Pedestrian User-Friendly Interface
SSAM	Surrogate Safety Assessment Model

TTC	Time To Collision
VISSIM	VerkehrInStadten-SIMulationsmodell
VISSIM COM	VerkehrInStadten-SIMulationsmodell Common Object Model
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background to the Research

Road Transportation system can be defined as the combination of road fixed facilities, flow entities and the control system that permits people and goods to overcome the friction of geographical space efficiently in order to participate in a timely manner in some desired activities (Papacostas and Prevedouros, 2008). Fixed facilities are the physical components that are fixed in space and constitute the network links in transportation system. Examples of these are roadways, railway track, pipes and transit terminal. Flow entities are the units that traverse the fixed facilities. These include all categories of vehicles, drivers and pedestrians. The control system consists of all entities that control the movement of road users such as vehicles and pedestrians. These permit the efficient and smooth operation of streams of vehicles for the reduction of conflict between the vehicles and other road users especially the pedestrians. The control combines signing, markings, signal systems and their underlying rules of operations. The signal system over the years has gone through various stages of automation (Chen *et al*., 2012)

Among other infrastructures involved in road transportation system, the most delicate and irreplaceable entity in the midst of all other physical devices are the pedestrians. They are therefore, the most vulnerable. The safety of human life is expected to be a major concern to the government, organizations and the general populace. There are different life challenges that could bring about the death of a person. Some of these challenges or situations are avoidable or preventable. Pedestrians are people walking or running on foot. According to National Highway Traffic Safety Administration report (NHTSA, 2013), a pedestrian is any person on foot - walking, running, jogging, hiking, sitting or sitting down who can be involved in a motor vehicle traffic crash. A traffic crash is defined as an incident that involves one or more motor vehicles where at least one vehicle is in transit and the crash occurs on a public traffic way, such as a road or highway. Crashes that occur on private property, including parking lots and driveways, are excluded. No matter how rich, powerful or highly placed in society, anytime one has to park his car and walk across some distance, he has become a pedestrian. Walking is an environmentally friendly and important mode of transportation. It constitutes the first and last part of almost any trip, regardless of what the main mode of transport is, and is especially important in connection to public transport trips. In fact walking is at the beginning and the end of any journey and the cheapest means of transportation (Johansson, 2013). Walking has health and environmental benefits such as increasing physical activity that may lead to reduced cardiovascular and obesity-related diseases. Many countries have begun to implement policies to encourage walking as an important mode of transport (WHO, 2013a).

Unfortunately, increase in vehicular traffic without adequate provision for walking pedestrians can lead to increased road traffic crashes and injury. Due to the dramatic growth in the number of motor vehicles and the frequency of their use around the world without adequate provision for pedestrian needs in roadway design and land-use planning, pedestrians are increasingly susceptible to road traffic injury (Agarwal, 2011).

It is then clear that a pedestrian has to share roads, streets, roundabouts, walk ways and such likes with other users like motorbikes, bicycles, vehicles and co-pedestrians as the case may be. This makes the safety of lives a serious issue that deserves road safety considerations. Looking at the nature of Nigerian roads, level of literacy of drivers and care-free attitude of Nigerians to road safety rules, there is no doubt, that pedestrians on Nigerian roads are vulnerable to vehicle-pedestrian crashes (Akomolafe, 2014). Country like USA spend a lot of money on research and implementation of technologies to make provisions for safety of pedestrians on the road (Markowitz *et al.,* 2008). Pedestrians are categorized as vulnerable road users (Armsby, 1996).

Pedestrian fatalities in Colorado were 16.5% of total fatalities in 2012 and 13.8% in 2016. Full details of this report are in Appendix P (CODOT, 2017). According to Van-Houten *et al.* (2013), in large cities of US, pedestrians account for 40% to 50% of traffic fatalities. In 2010, there were 4,280 pedestrian fatalities in the United States (NHTSA, 2012). It was also lamented in NHTSA (2017) that the pedestrian fatalities account for almost 6,000 deaths in 2016 which is the highest in two decades. Researchers cited distraction as the major factor responsible for this.

In Nigeria 4,260 deaths and 20,757 injuries were recorded in 2012 (NRSS, 2017). Hunter *et al. (*1996) indicates that lack of drivers' compliance to pedestrian crossing laws is associated with pedestrian motor vehicle crashes. Figure 1.1, is snapshot of four lanes urban road network as an example of pedestrian unfriendly environment indicating how difficult it is for pedestrians to cross. Figure 1.2, is an example of vehicle unfriendly environments, a snapshot of woods as traffic calming measures along Ankara - Zaria Road, Katina-State in Nigeria.

Figure 1.1 Pedestrian Unfriendly Environment (Sawers, 2008)

Figure 1.2: Vehicle Unfriendly Environment along kankara-Zaria road snapped on 15th September, 2014

Most of the time, the major traffic facilities are vehicle-centered. Most provisions for traffic solution address vehicular congestion and delay. Where communities on their own decide to make adhoc traffic calming provision, the resultant infrastructure are the dangerous woods on the road that can cause serious damage to vehicles. An intelligent traffic control system that will consider both the pedestrian right of way and its impact on vehicular traffic flows will be a way forward to improve safety.

1.1.1 Pedestrian Crossing

A pedestrian crossing is a point on a road where pedestrians traverse the road (Papacostas and Prevedouros, 2008). Pedestrian crossings, sometimes referred to as crosswalks, may be found at intersections or along road stretches. Marked crossings are designated by markings on the road, commonly white stripes. Signalized crossings include automatic traffic signals that indicate to pedestrians when they should cross. The place where two or more roads meet or cross each other is called an intersection. Intersections with traffic controls such as stop signs, markings or managed by authorized personnel are referred to as controlled intersections (Fisher, 2013). Intersections controlled by automatic traffic signals are called signalized intersections. Intersections that are not controlled by traffic signs, markings, authorized personnel or automatic traffic signals – leaving priority and traffic flow at the discretion of the road user – are referred to as uncontrolled intersections (WHO, 2013a).

The beginning of solution to vehicular/pedestrian clash called pedestrian crossing began in 1905 when direction signs were placed on wood in Los Angeles, pedestrian tunnels or subways in 1918, stop signs in 1930, and Zebra crossing that originated in Britain in 1951. The first known signalized crossing in Britain called push button was introduced by Manchester-based Forest City Ltd in 1929. On the same plane, in Southern California Ralph Dorsey the first traffic engineer developed and installed the first automated crosswalk on 14th January, 1929 in front of Luther Burbank Junior High School (Fisher and Ptoe, *nd*). Common pedestrian crossing devices nowadays are Zebra crossing, stop signs, traffic signals, human traffic wardens, overhead bridges, underpass and traffic calming measures like woods and street bumps on our roads (Akomolafe, 2014)

Despite many years of research and the development of guidelines for signs, signals, and markings by various countries, there are still many situations where pedestrians need assistance related to traffic control devices. Disabled pedestrians, old pedestrians, children are more vulnerable than others. More accessible pedestrian facilities around transit areas are still required in most developing countries (Bonisch and kretz, 2009). Majority of facilities are at times wrongly placed without foundational assessment of the needs of the people. Overhead bridges are not meant for the disabled and pedestrians with heavy loads. Fixed cycle traffic light allocates the same signal time when there were fewer or even no vehicles on the lane (Abdoos *et al.,* 2011). With the recorded death tolls, the devices are being evaluated from time to time to measure their effectiveness, hence, reason for continue research of what can be done to reduce pedestrian crash rate. Pedestrian crossing control presents a challenge for transportation and road professionals given the need to accommodate pedestrians safely in an interactive manner with other users of the transportation system (Montufar, 2013).

In a conventional traffic light controller, the traffic light changes at allocated fixed cycle times which obviously cannot yield the optimal solution. The system disregards the dynamic nature of the traffic load, which can reduce congestion and enhance safety (Alam and Pandey, 2014). Consequently, there is an urgent need for an intelligent traffic control algorithms to accommodate the dynamic nature of urban traffic that experienced long vehicular and pedestrian delay due to inefficient traffic light controls so as to improve pedestrian's safety. Dynamism encourages a fair share of right of way among various road users.

1.1.2 Challenges of Common Pedestrian Crossing

Several issues arise with implementation of most common pedestrian facilities like Zebra crossing overpasses (e.g. overhead pedestrian bridge) and underpasses. The level of use depends on convenience, security, and walking distances compared with alternative crossing locations. Pedestrians generally do not use these facilities if a more convenient route is available. Overpasses with multiple stairs are not user-friendly for the elderly or disabled pedestrians and most of the time dangerous in the night. Robbers can easily attack pedestrians in the night. Underpasses can be affected by flooding, and may quickly become dirty without regular maintenance (Chavan *et al.,* 2009)

The poor road maintenance culture in Nigeria further aggravates the unsafe state of pedestrian crossing the road. For example, the white paint on the Zebra Crossing often peel-off without replacement within reasonable length of time (Akomolafe, 2014).

1.1.3 Road Traffic Crash

A road traffic crash is a collision or incident involving at least one road vehicle in motion, on a public road or private road to which the public has right of access, resulting in at least one injured or killed person (Papacostas and Prevedouros, 2008). Included in these are: collisions between road vehicles; between road vehicles and pedestrians; between road vehicles and animals or fixed obstacles or with one road vehicle alone. Included are collisions between road and rail vehicles (WHO, 2013a). Figure 1.3 is a typical scene of vehicle-pedestrian crash in Lagos Nigeria, a man crushed to death and the woman with bleeding nose definitely has minimal chance of surviving.

Figure 1.3: Vehicle-Pedestrian Crash incident in Lagos, Nigeria. (www.codewit.com)

Zeeger *et al.* (2013) identified factors that affect pedestrian safety as lack of Sidewalks, High Traffic Volume, High Vehicle Speeds, Multiple Traffic Lanes, Lack of a Median (on Multi-lane Roads) and Presence of Transit. Each of these factors will increase the time pedestrian stay before the gap in vehicle streams can enable safe crossing.

1.2 Problem Statement

The major reason for the pedestrian-vehicular clash is the prolonged pedestrian's waiting time which makes the pedestrians to risk their lives to cross the road even when the gaps between the vehicle streams are not acceptably safe to do so (Niittymaki and Kikuchi, 1998; Aiswaria and Rani, 2013). The conflicting interests of both impatient drivers and waiting pedestrians need to be intelligently managed considering the day to day increase in the complexity of traffic management on various types of roads. Alam and Pandey (2014) optimized control timing to reduce congestion without considering pedestrian right of way. The typical conventional traffic light controls are still associated with heavy traffic which will not allow pedestrians to cross and at times lanes without vehicles are allocated right of way leading to a higher delay. According to WHO (2013b), more than one fifth of the people killed on the world's roads each year are not travelling in a car, on a motorcycle or even on a bicycle – they are pedestrians. According to the same report, there were clear geographic distributions of pedestrian mortality, with the proportion of pedestrians killed in relation to other road users being highest in the African Region (38%) and lowest in the South-East Asia Region (12%). Pedestrian deaths and injuries are often preventable, yet, in many locations, pedestrian safety does not attract the attention it merits (Van-Houten et al, 2013, Aworemi *et al*., 2010). An intelligent system will be a good solution to optimize the control signal timing thereby harmonizing the conflicting interests of vehicle drivers and pedestrians. (Zadeh, 1979)

1.3 Motivation for the Research

Understanding of pedestrian traffic needs is of practical importance when planning for road infrastructures. Quantitative models of vehicular traffic have long been incorporated in various town planning works without corresponding modeling of pedestrian traffic (Johasson, 2013; Papacostas and Prevedouros, 2008). There still exist roads in Nigerian cities without pedestrian crossing signs, meaning that pedestrians are left to cross at their risk (Odeleye, 2002). The necessity to plan for efficient pedestrian traffic control has not been an urgent one since pedestrian traffic is seen as no threat to the environment, hence models and observation of pedestrian traffic has not received much attention and resources as vehicular traffic (Agarwal, 2011). During planning for new infrastructures for vehicular traffic, it is a common thing to make predictions of future traffic situation to enable prioritization among various projects. This is also needed for pedestrians

The subject of this research is developing an intelligent vehicle-pedestrian traffic control system to harmonize the conflicting interest of drivers and pedestrians to improve pedestrian safety.

1.4 Aim and Objectives

A safety-driven intelligent traffic control that considers the delay conflict between the driver and the pedestrians will reduce crash rates and enhance safety. Therefore, this research aims at designing a safety-driven intelligent vehicle-pedestrian traffic control system.

The specific objectives are to:

a. develop an intersection signal system capable of intelligently providing right of way to pedestrian based on prevailing traffic conditions to improve safety;
b. represent interaction between vehicular traffic and pedestrian traffic in a fuzzy logic rule based system;
c. implement the intersection control system using traffic simulator;
d. evaluate the traffic control network performance using pedestrian delay and vehicular delay measurement against fixed time traffic control delay measurement.
e. analyze and evaluate pedestrian and vehicle trajectory data to determine potential crash-rate as a safety index.

1.5 Research Method

Related literatures on road traffic infrastructures, traffic management, intelligent transportation systems, pedestrian traffic models and traffic simulators were reviewed. The parameters to be used to evaluate traffic management and pedestrian facilities were identified through literatures. Microscopic simulation modeling tool was used because microscopic method allows detail characteristics of Pedestrians and Vehicles to be captured.

An architectural framework was developed for interaction between traffic entities: vehicle and pedestrians taking into consideration varying conditions such as automatic detection of pedestrians, the waiting time of pedestrians, the number of pedestrians waiting to cross the road, vehicle queue length and weather condition. Fuzzy logic based reasoning model for vehicular/pedestrian interactions was developed. The reasoner was implemented using Matrix Laboratory (MATLAB).

VISSIM Microscopic simulation software was used to implement the road traffic network, comprising of vehicle and pedestrian links as well as the flow entities. The interfacing of MATLAB and VerkehrInStadten-SIMulationsmodell (VISSIM) was done using VISSIM COM coding platform.

The evaluation of the system was done through various configuration scenarios and comparism made and conclusions were highlighted.

1.6 Contribution of the Thesis to Knowledge

a. The inference model developed is a contribution to technological development to solve conflicting interest of drivers and other road users, especially pedestrians at intersections. This will prevent marginalization of any of the road users in allocation of the right of way.

b. The safety driven traffic model developed is a contribution to crash reduction scheme. The implementation of the traffic model proved that the crash rate can be reduced at four way intersection.

c. The interactive framework for incorporation of the traffic model and inference models is a way of quantitative estimation of level of service at intersection which traffic engineers and town planners can use to determine where such facilities are needed based on traffic volume (land use).

d. The research provides an optimal signal control scheme that minimized both vehicle and pedestrian delay at intersection

e. The estimation of pedestrian delay based on vehicle count from unsignalized intersection from Kano metropolis gave quantitative values of estimated pedestrian delay as vehicle volume increases. This is an indication of the need for pedestrian crossing facility in that area.

1.6 Organization of the Thesis

The rest of the thesis is organized as follows.

In Chapter two, literatures were reviewed on causes of vehicle – pedestrian crashes, existing pedestrian safety treatments, road complimentary infrastructures, road traffic management and intelligent transportation system. Traffic micro-simulation models and traffic network simulators were also discussed and the research gaps identified under summary of literatures.

Chapter three presented the proposed conceptual model which comprises of the vehicular, module, pedestrian module and the intelligent fuzzy logic system. The designed architectural framework discussed as well as the data communication flow within the framework. The operational algorithms for each module were highlighted and Fuzzy inference model developed with the corresponding rules formation developed using MATLAB.

In Chapter four, analytical estimation of pedestrian delay was computed and discussed based on vehicle counts obtained from Kano. Various implementation phases as unsignalized, signalized fixed time and the intelligently influenced traffic network scenarios were modeled using VISSIM traffic simulator. The interfacing of VISSIM simulator with the intelligent fuzzy logic system was discussed.

Chapter five discusses the results of the simulation scenarios based on vehicle delay and pedestrian delay as evaluation parameters. Simulation trajectory data analyzed and result discussed in terms of Time To Collision (TTC) as safety index. Various results were interpreted; comparisms were made between traffic control schemes, Alam and Pandey (2014), Agarwal (2011) and standard delay values.

Chapter six summarized the research, draw conclusion and discussed the recommended future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Literature reviewed in this chapter covers research on traffic safety measures, road complimentary infrastructures, road traffic management and intelligent transportation system. The chapter is organized as follows. Section 2.2 outlines causes of pedestrian crashes, Section 2.3 reviewed road complimentary infrastructures, and Section 2.4 discussed research work on evaluation of pedestrian facilities, Section 2. 5 centered on pedestrian models while in Section 2.6 intelligent systems were reviewed. Section 2.7 highlights pedestrian safety parameters, in section 2.8 modeling and simulation of systems discussed, Section 2.9 traffic management simulators were reviewed. Section 2.10 introduces MATLAB and Section 2.11 summarizes the literatures and identified research gap.

2.2 Causes of Pedestrian Crashes

Ifesanya *et al.* (2009) conducted a survey of pedestrian/vehicular crash in a tertiary hospital in South Western part of Nigeria. A total of 184 patients with a mean value of the ages of 31.4 years were studied; the mortality rate was 31.0%. This obviously demands attention; pedestrian safety is a major issue in any country. According to NHTSA (2013), pedestrian crash rate was highest from 2011 through 2013, which is 14% as reflected in Table 2.1.

Table 2.1: Pedestrian Fatality Rate from 2004-2013 (NHTSA, 2013)

Year	Total Fatalities	Pedestrian Fatalities	Percentage of Pedestrian to Total Fatalities
2004	42,836	4,675	11%
2005	43,510	4,892	11%
2006	42,708	4,795	11%
2007	41,259	4,699	11%
2008	37,423	4,414	12%
2009	33,883	4,109	12%
2010	32,999	4,280	13%
2011	32,479	4,457	14%
2012	33,782	4,818	14%
2013	32,719	4,735	14%

A five years (2007 – 2011) range crash report from across Nigeria is represented in Table 2.2, this five year range report recorded average of 5.0 fatality rate per 100,000 population.

Table 2.2: Pedestrian crash data in Nigeria (Sumaila, 2013)

Year	Number of cases	Number killed	Fatality rate per 100,000 population	Fatality rate per 10,000 vehicles
2007	8,477	4,673	9	NA
2008	11,341	6,661	6	NA
2009	10,854	5,693	5	NA
2010	5,330	4,065	4	NA
2011	4,765	4,327	4	6
Average	8,153	5,084	5	NA

For the purpose of this research, pedestrian crash data were obtained from road safety command in Kano. This report recorded 495 pedestrian/vehicular crashes from 2007 to 2014 in Kano State. (See Appendix F).

Traffic management that will reduce crash rate must effectively consider the conflicting interest of waiting pedestrians and anxious drivers. This is an area that needs urgent research attention. An intelligent system that will take into consideration major underlying variables such as pedestrians waiting time, walking speed, total number of pedestrians that characterized the crossing situation of pedestrians traffic and vehicular traffic characteristics such as number of vehicles on each lane and vehicular delay will manage the signal timing more efficiently (Zadeh, 1975; Hoogendoorn-Lanser, 1998). Microscopic traffic modeling is a technique that takes into consideration the detail characteristics of the entity in view. It is a tool that can be used to bring to picture the interactions between the traffic components and the pedestrians (Alexandersson and Johansson, 2013)

Intelligent pedestrian traffic control system can manage the timing effectively, reduce delay for both vehicles and pedestrians and thereby prevent crashes and enhance safety, encourage walking which will in turn promote good health and reduce trips using private cars. When roads are safe people will take delight in walking short distances instead of driving that increases atmospheric pollutions as vehicles emit carbon dioxide. Many studies have examined the effect of various intersection and traffic characteristics that impact pedestrian safety based on the available crash values, and field observations. (Bonisch and Kretz 2009; Chertock *et al.,* 2014)

Aworemi *et al.* (2010) investigated the causal factors of road traffic crashes in order to establish the relationship between human characteristics, vehicular characteristics, roadway characteristics, environmental characteristics, and road traffic crashes in the study areas. Data were obtained from a total of 352 respondents, from four out of six states that make up of southwestern Nigeria using stratified random sampling technique. Regression Analysis was adopted in analyzing the data obtained. The investigation revealed that human, vehicle, roadway and environment had significant contribution of about 79.4% on the road traffic crashes in the study area. Regression Analysis was adopted in analyzing the data obtained. The initial model is represented in Equation (2.1)

$$Y = a_0 + b_1X_1 + b_2X_2 + b_3X_3 \ldots\ldots\ldots b_nX_n + U_e \qquad (2.1)$$

where

Y – Dependent variable,

a_0 - Constant, X_i = Explanatory variables

b_i - Parameters to be estimated (i = 1, 2, 3, - - - -- n)

U_e - Error term or disturbance term

X_1 - human characteristics

X_2 - vehicular characteristics

X_3 - roadway characteristics

X_4 - environmental characteristics

The result of multiple regression estimation technique is shown in Equation (2.2)

$$Y= 624.8192+3.7661X_1+2.1194X_2+3.320X_3+2.5270X_4+ U_e \qquad (2.2)$$

The work concluded that human (pedestrians and drivers) variable represented as (X_1) had a coefficient of 3.7661 which is the highest and therefore the major factor in causing crashes on the roads. This is an indication that it is necessary to provide an improved measure to reduce crashes due to prolonged pedestrian waiting time.

2.3 Pedestrian Road Complimentary infrastructures

These comprises of all signalized and unsignalized measures placed on the road network to assist pedestrians to share the road with vehicles and other road users.

2.3.1 Signalized Pedestrian Treatment

Signalized pedestrian crossings consist of pedestrian facilities with signal displays and lightings. Signalized facilities give priority to vehicles, and pedestrians are allowed to cross only when the signals halt vehicle traffic on the road. There is the need to intelligently allocate the signal timing to give pedestrians time enough to complete their crossing before the signals changed to vehicle traffic movement. Also, signalized pedestrian crossings rely on compliance with traffic signals, which can be poor in some instances. Signalized crossing can be used at midblock locations or incorporated into existing traffic signals at intersections. Pedestrian phasing should be considered at all signalized intersections where pedestrians are likely to be present.

2.3.2 Unsignalized Pedestrian Treatment

Unsignalized pedestrian crossings mainly consist of different types of signs, beacons and painted road markings. Pedestrians are meant to have right of way over vehicles, but in many regions drivers do not stop for pedestrians. This makes unsignalized pedestrian crossings of few benefits and may actually be hazardous. These crossings are only suitable in road network with low traffic volumes and speeds. Achieving the highest level of safety, operations, or accessibility at a given intersection may come at the detriment of one or both of the other road users. Safety and operations are supposed to be correlated—that is, when one improves, the other benefits, as well. However, this is not always the case. An improvement that increases vehicular speeds may result in higher crash severity. Additionally, modifications to an intersection that improve the safety and operational conditions for vehicular traffic may have the opposite impact on non-motorized users. Unsignalized measures comprise of measures such as crosswalks, sidewalks, signs and beacons. (UIIC, 2015)

a. Sidewalks

A sidewalk (footpath or footway) is a path along the side of a road. A sidewalk may differ in size (height) and is normally separated from the vehicular section by a curb. In some places, the same term may also be used for a paved path, trail or footpath that is not next to a road, for example, a path through a park (Huang and Cynecki, 2001).

Sidewalks play an important role in transportation, as they provide a safe path for people to walk along that is separated from the motorized traffic. In suburban areas, sidewalks help to provide equal access to people who cannot drive, notably children, the elderly and the economically disadvantaged. Sidewalks also play an important role in accommodating people that, while perfectly able to drive, may choose not to, depending on the length and type of trip they are undertaking - such as a walk to a local shop, a walk for recreation or physical exercise, or taking a pet (such as a dog) for a walk. This facility obviously is not meant for crossing the road.

b. Pedestrian Bridge

Pedestrian bridges are overhead bridges made for pedestrians and bicyclists to safely cross busy roads without conflicts with vehicles. Moreland (2015) in Traffic Data Incorporation (TDI) carried out investigation in Columbia Heights, Minnesota. This location had a pedestrian bridge over a busy four-lane divided road with turn lanes. At the signalized intersection, the major road travels north-south and the pedestrian bridge provides for east-west travel on the south side. There were no marked east-west crosswalks across the major road. Other characteristics of the intersection according to the report were: The distance from curb to curb is about 140 feet, the pedestrian bridge adds about 700 feet to the crossing distance and the major road has about 25,500 vehicles per day. Using two video cameras, the first camera pointed at the pedestrian bridge access on one side of the road and the other camera focused on the intersection, a 24-hour count of how pedestrians and bicyclists cross this major road were conducted. From the 24 hours of data collection, approximately 44% of 170 pedestrians and bicyclists crossed using the pedestrian bridge. That means the 56% preferred convenience to safety. In most cases people tend to view the extra distance as a burden that will incurred additional travel time.

Figure 2.1 is a picture of a pedestrian bridge in Lagos, Nigeria and people who abandoned the bridge, risking their lives to cross the road. The bridge is a safety measure but does not cater for the disabled and the pedestrians with heavy load. According to Oluponda (2015) the major reasons why pedestrians do not use pedestrian bridges in Lagos are:

i. It takes extra effort to climb up the stairs, and go down again. By crossing directly it can save effort and time.
ii. People worry about their safety, the fear of thieves and kidnappers on the bridge especially during night hours.
iii. There may not be regular maintenance of the structure. They could be dirty, and rusty.

Figure 2.1: Pedestrians crossing without using the pedestrian's bridge (www.mydailynewswatchng.com)

c. Pedestrian Traffic signs

STOP signs are devices that are used to regulate, warn, or guide traffic as part of traffic control measures. A stop sign is used to control traffic and is usually found at road intersections. Stop signs instruct drivers about the right-of-way and ensure proper notice is taken to avoid accidents. Standard stop signs are red octagons with "STOP" printed in white letters or yellow circle with red edges with "STOP" printed in black and walking pedestrian in the centre. Where it is placed at intersection, the driver is expected to stop and proceed only if the way ahead is clear, and after obeying available rules regarding right-of-way. MUTCD (2005) recommends the following traffic situations for usage of STOP signs.

i. To stop the direction that conflicts the most with established pedestrian crossing activity or school walking routes
ii. Stopping the direction that required drivers to use lower operating speeds due to obscured vision, dips, or bumps.

iii. To stop the direction that has the longest distance of uninterrupted flow approaching the intersection.

iv. When needs arise to stop the direction that has the best sight distance to conflicting traffic

Figure 2.2 and 2.3 are examples of traffic signs which are meant to indicate pedestrian crossing to the vehicle drivers. This was often ignored by drivers on high speed. Figure 2.3 is not just STOP sign, it also an indication of elderly slower pedestrians crossing from that neighbourhood.

Figure 2.2: Pedestrian Crossing and vehicle stop Signs
(https://www.google.com.ng/search?q=pedestrian+sign)

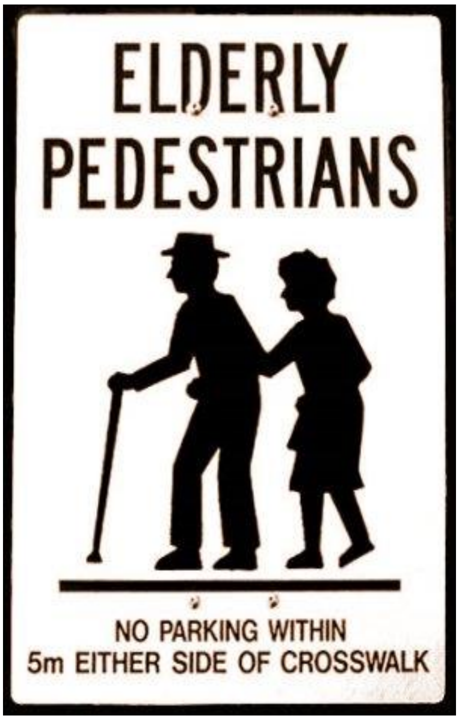


Figure 2.3: Elderly Pedestrian Signs (https://www.google.com.ng/search?q=pedestrian+sign)

d. Zebra Crossing

Traditionally, the essence of zebra crossing on the road is primarily to stop vehicle stream so as to allow pedestrian(s) to cross the road lanes safely. Especially when it has not been possible to maintain a perfect and complete segregation between these two important road users. However, the attitude of road users on zebra crossing in Nigeria renders ineffectual the safety benefit of this safety measure. Notably, the following negative attitudes are exhibitioner on zebra crossing by road users in major cities in Nigeria; Zebra crossings are obstructed due to on-street parking, Vehicles in traffic jam stand on zebra crossing, Pedestrian stands aloof from this safety device and Motorists raced across the zebra crossing.

The poor road maintenance culture in the metropolitan further aggravates the unsafe state of this safety device. For example, the white paint on the Zebra Crossing often peel-off without instant replacement. In addition, supplementary component of the road environment that are supposed to alert the road users of the need to use the zebra crossing, as well as the necessity to obey it are virtually not available. Among these supplementary components are: special lighting device for pedestrians crossing, steady and flashing beacons, overhead floodlight and traffic control lights that give right of the way to pedestrians. Ironically, zebra crossing points are abandoned, and paradoxically becomes a danger crossing point for the pedestrian most of the time (Odeleye, 2002). Hence the need for a sensitive pedestrian crossing for improved safety. Figure 2.4 is the representation of major crosswalk marks which if placed supposed to be a mark of pedestrian opportunity to cross.

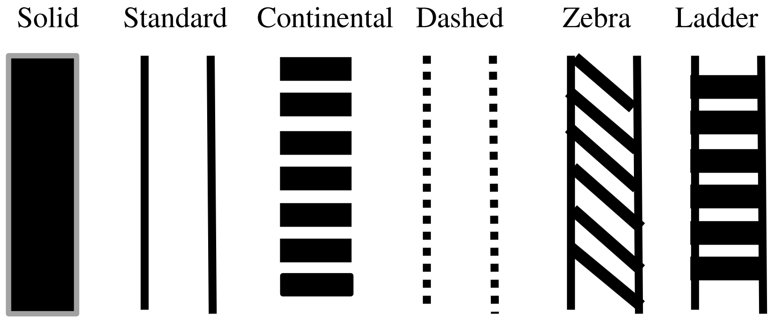


Figure 2.4: Examples of crosswalk marking patterns (Mead *et al.*, 2014).

f. Traffic Calming

The objective of traffic calming is usually to reduce traffic speed or volume, reduce conflicts between local traffic and through traffic, make it easier for pedestrians to cross the road, and reduce traffic noise. Traffic calming can be applied both in residential areas and on roads that have commercial roadside development. A 2001 meta-analysis of 33 studies of traffic calming by Cicchino *et al.*(2013) concluded that area-wide traffic calming schemes reduced the number of injury collisions for all road users by about 15 percent, with greater effects on residential streets (a reduction of about 25 percent than main roads). Measures that are part of traffic calming includes Narrowing driving lanes, often by widening sidewalks, curb bulbs, Providing raised crosswalks or speed humps as shown in Figure 2.5.

Figure 2.5: Two vehicles slow down as they pass over a speed bump. Source: (Huang and Cynecki, 2001)

g. Roundabouts

Modern roundabouts are a device to control the flow of traffic at intersections without the use of traffic signals or stop signs. While it has been demonstrated that roundabouts are safer for motorists than signalized intersections, the impact of roundabouts on pedestrian safety, especially for visually-impaired pedestrians, has been a subject of debate. One factor that complicates the ability to analyze roundabout performance is the low number of pedestrian crashes at any given intersection before and after roundabout conversion.

Traffic calming devices have their disadvantages. For example, these treatments can hinder activities such as street cleaning and snow plowing, may impede emergency vehicle access, and may affect drainage. The noise of vehicles going over speed humps, raised crosswalks, and raised intersections may disturb nearby residents (Kretz, 2009).

2.4 Assessment of Pedestrian Facilities

Chen *et al*. (2012) in a research work titled 'The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections' evaluated the relative effectiveness of five countermeasures in New York City. They are: increasing the total cycle length, Barnes Dance, split phase timing, signal installation, and high visibility crosswalk. The research aim at examining potential trade-offs in their effectiveness in reducing pedestrian crashes and multiple vehicle crashes. The work uses estimation of a negative binomial model with the Generalized Estimating Equation (GEE) method to evaluate the effectiveness of the chosen facilities. Using a large urban area, the study suggests that the four signal-related countermeasures are more effective in reducing crashes than high visibility crosswalks. The findings reveal that over emphasis in pedestrian safety facilities creates increase in vehicular delay and there are trade-offs to be considered between improving pedestrian safety and motorist safety. The work recommends the need to balance the time allocation for different groups of road users at the intersections so that the improvement of the safety of one group does not compromise that of other groups.

The work was able to achieve reduction in crash rate after the pedestrian crossing improvement but does not consider the additional delay incurred on vehicle stream. The subject of the proposed research is to model a system that will dynamically take care of time allocation of both pedestrians and motorist based on traffic situations to reduce the conflict and increase safety.

Sawers (2008) carried out a research to compare the crash rate at roundabouts and crossroads, the result recorded 1,172 fatal crashes, 12,112 slight injuries at urban roundabout and 493 fatal crashes with 4,463 slight injuries at rural round about. This work was out to gather information on pedestrian safety at round-about as a traffic calming measure and crosswalk as a pedestrian facility. The result is a clear indication that the presence of those facilities has not solved the problem of pedestrian safety. The work evaluated the existing facilities and brought out their measure of effectiveness but did not proffer a better solution. This is why it is necessary to design an intelligent system to harmonize pedestrian waiting time and vehicle delay to reduce conflict and thereby enhance safety.

Despite many years of research and the development of guidelines for signs, signals, and markings by various countries, there are still many situations where pedestrians need assistance related to traffic control devices. Disabled pedestrians, old pedestrians, children are more vulnerable than others. More accessible pedestrian facilities around transit areas are still required in most developing countries (Zeeger *et al*., 2013). The proposed intelligent system will took into pedestrian delay factors as well as vehicular delay factors.

Ulfarsson *et al.* (2010) carried out a research on the analysis of faults in pedestrian vehicular crashes. The work based on multinomial logic model concluded that results from traffic safety studies are not necessarily transferable between distant geographic locations, and that location-specific safety research needs to take place. They also emphasized the need to further study the specific effects of the design of the pedestrian facility on safety. The research analyzes the causes of crashes and emphasizes the need for a good design of pedestrians crossing facility to enhance safety.

2.5 Pedestrian Traffic Models

Modeling is a technique that is mostly used to measure or quantify situations to enable prediction or projection of future situations of the system being represented by a model.

Kuan-min *et al.* (2010) developed a pedestrian delay estimation model for intersections considering automobile-pedestrian conflicts induced by driver's behaviour of not giving way to pedestrians. In order to test the effectiveness of this proposed delay estimation model, VISSIM simulator was used to model signalized and unsignalized intersections. The delay values derived from this proposed model had a closed range with the observed values. The work confirmed pedestrian delay as a parameter contributing to crash rate but did not proffer solution to the crashes. Effective traffic control and right of way was not part of the research.

Agarwal (2011) developed potential conflict models to quantify potential interactions between pedestrians and vehicles at various intersection designs. The work aimed at estimating potential conflict between pedestrians and vehicles. The modeling was based on linear regression models for signalized, unsignalized and roundabout intersections. The result revealed that pedestrian-vehicle conflicting volumes, the number of lanes that pedestrians are exposed to, the percentage of turning vehicles, and the intersection conflict location were found to be significant predictors for estimating pedestrian safety at signalized and unsignalized intersections. For roundabouts, the pedestrian-vehicle conflicting volumes, the number of lanes that pedestrians have to cross, and the intersection conflict location were found to be significant predictors. The model was used to compare alternative intersection designs in USA, the model was tested using signalized environment and had potential conflict of 6.76. The work is a preventive safety measure to enable town planners and engineers to make provision to prevent the predicted conflict. The management of the right of way was not considered in the model. Exploring microscopic simulation in considering the immediate pedestrians situation and other traffics will provide means of analyzing pedestrians and vehicles interaction for improve safety (Alexandersson and Johansson, 2013). A positive effect of handling pedestrian traffic needs along with vehicular traffic will be an improvement on the safety status of walking as a mode of transportation.

Johasson (2013) developed a micro simulation platform for pedestrian traffic. The Pedestrian Traffic Simulation Platform is based on the Social Force Model mostly used for evaluation of proposed designs of pedestrian facilities. The thesis pointed out that Social Force Model (SFM) mostly used in generation of pedestrian traffic which is being used to assess the necessity of pedestrian facilities does not take into consideration the impact of waiting pedestrians on the movement of walking pedestrian. The work proposed an extension to SFM to take care of this. In modeling the waiting pedestrians, the research introduced three pedestrian waiting models to Social force model frame work and compared the delay impact of the different models of waiting pedestrians on the mean delay of each walker. The result demonstrated the delay impact of waiting pedestrians on simulation of pedestrian traffic. An independent simulator based on enhanced social force model to proof that waiting pedestrian has impact on generation of pedestrians was developed. Other factors that can affect pedestrian traffic like weather and road/path characteristics were not considered. Traffic control and safety measures were not considered as well. This is why a research on simulation of pedestrian traffic considering various characteristic surrounding pedestrian traffic and intelligently harmonizing it with vehicular demand at intersection is a necessity.

Kothuri (2014) made use of micro-simulation software VISSIM to analyze delays resulting from varying pedestrian and vehicle volumes on a network of three intersections in Portland. From a pedestrian's point of view, free operation was found to be always beneficial due to lower pedestrian delays. However, from a system wider perspective, free operation was found to be beneficial only under low-medium traffic conditions, while coordinated operation showed higher performance under heavy traffic conditions, irrespective of the volume of pedestrians. Investigation into Safety and efficiency tradeoffs was not considered but one of the areas of recommendation for further research.

2.6 Intelligent Transportation Systems (ITS)

The transfer of human thought and reasoning into technology is the bedrock of intelligent systems. The introduction of this in to transport technology gave birth to intelligent transportation systems which are an umbrella term for application of information and communication technology to transportation infrastructures and the associated flow entities (Pedestrians and Vehicles). Intelligent Transportation System (ITS) has been used to discover ways of improving safety, reduce congestion and emissions, as well as enhancing productivity (Hashim, 2011, Chattaraj and Panda, 2005). Elements of transportation systems are been embedded with microchips and sensors that enable information collection and communication. This is one of the paths that enhance linkage of transportation system to cloud computing and Internet of things. (Parulekar *et al.*, nd; Bilal and Jacob, 2007). The performance expectation from ITS is an adaptive signal control systems that perform real-time optimization of traffic signals across road network, adjusting signal timing based on prevailing traffic conditions, demand, and system capacity (Lee, 2008; Hui *et al.,* 2014).

Armsby (1996) aimed at assessing whether the concept of Intelligent Pedestrian Device (IPD) would be socially acceptable and what design criteria might be outlined to meet the pedestrian safety needs. The investigation was carried out using questionnaire. The results suggest that vulnerable pedestrians are more positive about the device than the more able-bodied pedestrians. The work explains that with education and marketing, the IPD could gain a degree of social acceptance. The work was able to develop preliminary specifications for the IPD based on knowledge about human behavior. An outline of design criteria for basic and sophisticated portable IPDs was given, and alternative functions are suggested. The device is expected to monitor traffic movement in relation to the user's location ·and give him or her information about whether it is safe to cross the road. It is recommended that further work be concentrated on developing software and hardware for fixed modes of IPD. This is also an indication for an intelligent pedestrian facility that can sense the presence of pedestrians and control the traffic for pedestrian safety.

In trying to make controlling traffic light more efficient, Chavan *et al.* (2009), exploited the emergence of intelligent traffic light controller that makes use of Sensor Networks along with Embedded Technology. The timings of Red, Green lights at each crossing of road were intelligently decided based on the total traffic on all adjacent roads. The work aims at optimization of traffic light switching to increase road capacity and traffic flow, and thereby prevent traffic congestions. GSM cell phone interface was provided for users who wish to obtain the latest position of traffic on congested roads which is very useful to car drivers who may wish to take an alternate route in case of congestion. Use of GSM cell phone while driving might cause distractions and increase risk of pedestrian/vehicular conflict especially in Nigeria. This work does not include pedestrian crossing, hence the need to design an intelligent system to take care of pedestrians

Jaworski (2013) proposed a two-step traffic management method that uses ITS-Cloud to deliver a detailed traffic simulation image and integrate an adaptive intersection control algorithm with a microscopic prediction mechanism. The aim was to predict the traffic situation and advise the incoming vehicles as well as optimized the traffic control situations. The research aim is to enable the intersection controller to advise incoming vehicles and at the same time responding to varying traffic in a timely manner. A measure of intelligence was involved in this work with special focus on vehicular traffic optimization. Pedestrian traffic need at intersection with vehicular traffic is not part of the research consideration, hence, the need for an intelligent system that encompasses pedestrian traffic with vehicular traffic to reduce pedestrians waiting time and thereby improve safety.

Kheradmandi and Strom (2012) presented a prototype Case-based Reasoning (CBR) system to execute traffic at a signal controlled pedestrian crossing. Intention-based Sliding Doors system created by another research work was integrated for interpreting the intention of pedestrians at the crossing. The system was created as an Open Services Gateway initiative framework (OSGI) bundle and uses the Cooperative Vehicle-Infrastructure System (CVIS) framework to communicate with other traffic systems. The architecture of the case-based system is represented in Figure 2.6 and the pedestrian delay presented in Table 2.1. The delay is minimal when traffic volume is low. The limitation of the design is that the computation time will increase as the number of cases increases. Pedestrian detection goes through an intention based system that identified the pedestrian that intend to cross from those just walking around. The tendency that some pedestrian might have even cross before the system finish analyzing their intentions is very high.

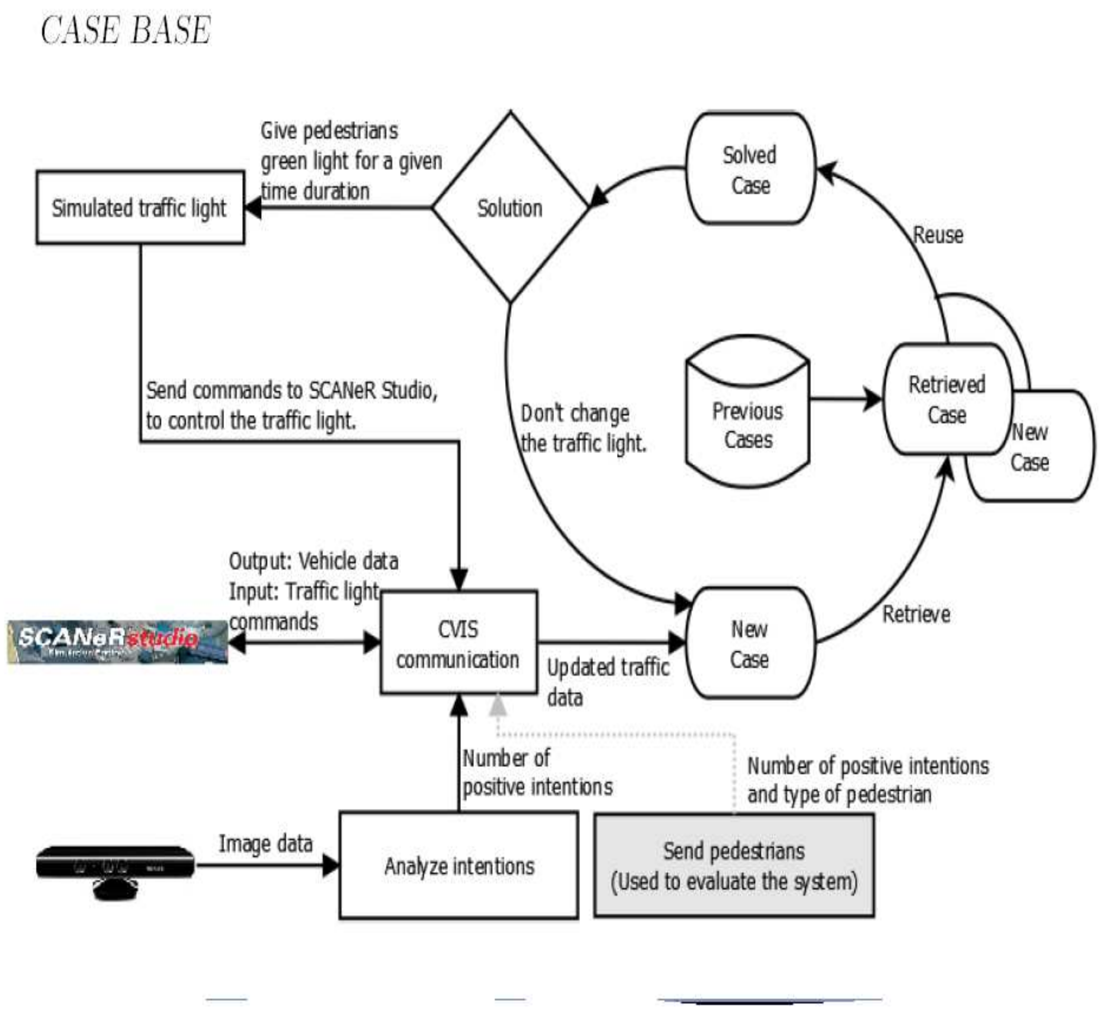


Figure 2.6: Case-based pedestrian traffic controller (Kheradmandi and Strom, 2012)

Table 2.1: Comparative Pedestrian Delay of Fixed cycle and CBR system (Kheradmandi and Strom, 2012)

Vehicular Flow	Average Pedestrian Delay During Fixed cycle traffic control (sec.)	Average Pedestrian Delay During CBR control traffic(sec.)
172	28.2	5
480	28.2	9.1
974	26.4	25.1
986	26.4	25.4
956	26.1	25
828	27.4	25
979	26.4	30.9

2.6.1 Fuzzy Set and Fuzzy Logic

In 1965, fuzzy sets were introduced by Zadeh to represent data and information possessing no statistical uncertainties. The set was designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision peculiar to many problems. This theory proposed the making of Boolean membership function values of False (F) and true (T) to operate over the range of real numbers [0, 1]. A fuzzy set can then be defined as a class with unsharp boundaries. A fuzzy set is a set without crisp boundaries. The transition between "to belong to a set" and "not to belong to a set" is gradual. Mathematically, we can define a fuzzy set *A* in *X* as a set of ordered pair:

$$A = \{(x, \mu_A(x)) \mid x \in X\} \qquad (2.3)$$

where $\mu_A(x)$ is called the membership function (MF) for the fuzzy set *A*. The MF maps each element of *X* to a membership value between 0 and 1. (Lin *et al.,* 2009; Zadeh, 1965)

Zadeh extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural terms. This new logic for representing and manipulating fuzzy terms is called fuzzy logic. Fuzziness depends on fuzzy set theory and fuzzy logic is a part of that theory. Fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership rather than on crisp membership of classical binary logic. Unlike two-valued Boolean logic, fuzzy logic is multi-valued. It deals with degrees of membership and degrees of truth. Figure 2.7 is a representation of Boolean logic with sharp boundary of either true or false represented with 1 or 0 and multi-valued logic with gradual changes from white to black thereby giving multiple range of values. (Hashim, 2011)

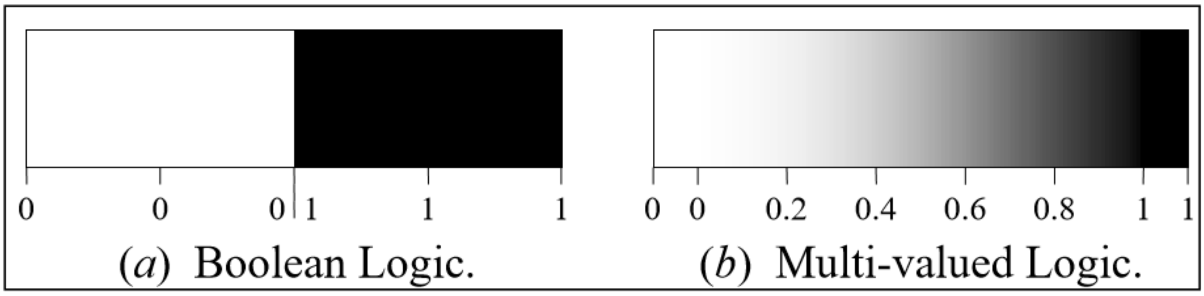


Figure 2.7: Boolean and Multi-valued Logic representation (Hashim, 2011)

Fuzzy logic uses the continuum of logical values between 0 (completely false) and 1 (completely true). Instead of just black and white, it makes use of spectrum of colours, accepting that, things can be partly true and partly false at the same time. Figure 2.8 is a plot of universe of discourse of variable height on x axis and degree of membership, which is degree of belonging on y axis.

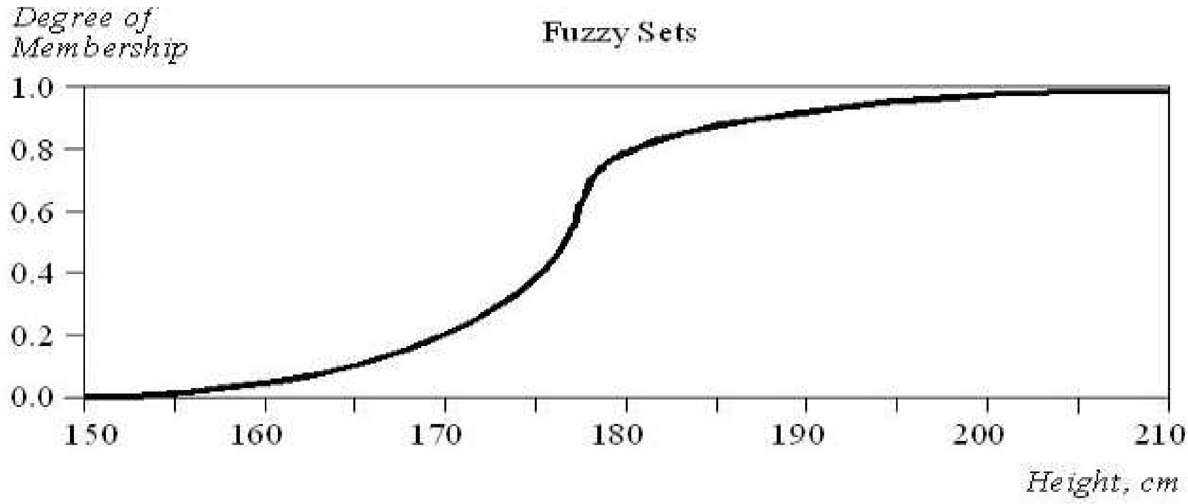


Figure 2.8: Fuzzy sets representation (Hashim, 2011)

The universe of discourse is the range of all possible values applicable to a chosen variable. Accordingly, the universe of men's heights consists of all tall representations. The y-axis represents the membership value of the fuzzy set. The fuzzy set of tall men maps height values into corresponding membership values. At the root of fuzzy set theory lies the idea of linguistic variables. A linguistic variable is a fuzzy variable. In fuzzy expert systems, linguistic variables are used in fuzzy rules. Fuzzy rules consist of set of IF (condition) THEN (implication) statements. For example: IF project_duration is long THEN completion_risk is high.

Fuzzy set theory has a number of branches which are: Fuzzy mathematical programming, Pattern Recognition, Decision Analysis, Fuzzy Arithmetic, Fuzzy Topology and Fuzzy Logic. Making use of fuzzy logic, the control algorithm can be expressed using simple rules and human language. This additionally improves robustness of the control algorithms. Fuzzy logic control (FLC) has proven effective for a complex optimization problem with multiple objectives, uncertain information, and vague decision criteria. Traffic signal timing lies in this category. (Chen *et al.,* 1990)

2.6.2 Application of Fuzzy Logic in Intelligent Traffic Control System

According to Zadeh (1975), expressing any natural phenomenon by mathematical expressions does not always guarantee exact capturing of the phenomenon and its implications. When phenomenons on human ideas are expressed linguistically, chance of proper capturing of the phenomenon increases. Fuzzy logic based on approximate reasoning can be expressed linguistically to capture the inherent vagueness of human mind; thus, it can be applied to the areas which involve human decision making like supervision, monitoring, planning, and scheduling. Intelligent transportation system is part of town planning solutions. Applications of Fuzzy Logic in Transportation Engineering include: Traffic Flow Modeling, Car Following Behaviour Traffic Flow Modeling, Transportation Planning, and Traffic Control at Signalized Intersection, Ramp–metering, Parking Garage, Traffic Monitoring and State Estimation. (Hoogendoorn-Lanser, 1998; Moreland, 2015).

In fuzzy logic, exact reasoning is viewed as a case of approximate reasoning. Values are expressed as a matter of degree. Knowledge is interpreted as a collection of elastic or equivalent and inference is expressed as a process of propagation of elastic constraints. Therefore logical system can be fuzzified (Zadeh 1979, Chattaraj and Panda 2005).

Lu and Noyce (2009), evaluated various signaling alternatives; Pedestrian Actuated (PA), Pedestrian User-Friendly Interface (PUFFIN), Pedestrian Light Controlled (PELICAN) and High intensity Actuated Crosswalk (HAWK). The work concluded that they were geared toward pedestrian need without consideration for vehicular traffic. FLC signal system was developed for mid-block crossing based on PUFFIN algorithm. The fuzzy based system evaluates the traffic situation before interrupting the vehicular traffic. The limitation of this work is that weather variable is not considered, the problem of pedestrians pushing the button and turning away was not resolved in the design. With embedded system sensors can be used to sense the actual presence of pedestrians.

Tan *et al.* (1996) describes the design and implementation of an intelligent traffic lights controller based on fuzzy logic. A software was developed to simulate the situation of an isolated traffic junction based on the designed fuzzy logic system. This design is diagrammatically represented in Figure 2.9. The distance D is the distance between the two sensors. This was used to count incoming vehicles and the number of vehicles discharged. A simulation experiment was carried out to compare the performance of the fuzzy logic controller with a fixed-time conventional controller. It was observed from the results that the fuzzy logic control system provides better performance in terms of total waiting time as well as total moving time.

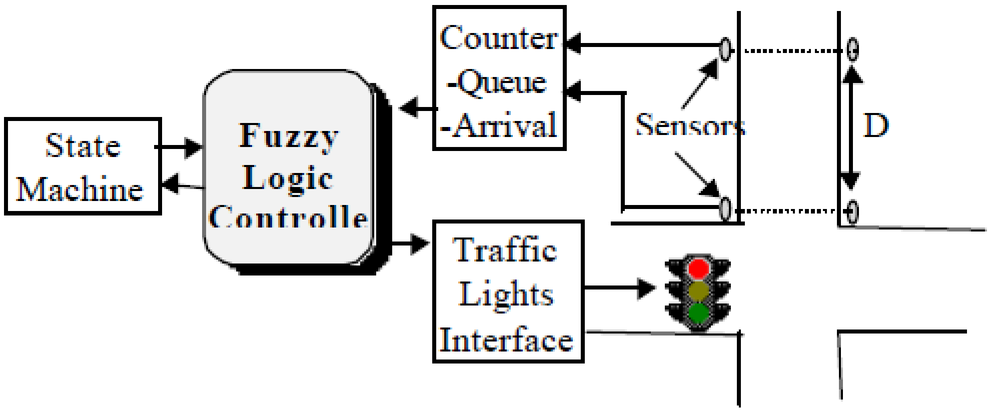


Figure 2.9: Representation of Fuzzy logic based traffic controller (Tan *et al*., 1996)

Aiswaria and Rani (2013) designed an intelligent fuzzy controller for a four phase cross junction to solve congestion problem in a two lane cross junction in Malaysia. The design has two modes of operations, peak hour operation and non-peak hour operations. Signal time allocation was intelligently allocated according to vehicular volume from road sensors located 100m away from the stopping line. Minimal delay for vehicles was achieved as compared with fixed time controller. The work however does not include pedestrian's facility and weather variables were not included in the fuzzy design.

Zarandi and Rezapour (2009) proposed a changeable phase-sequence signal control algorithm. The fuzzy signal control system (FSCS) contains fuzzy phase selector and fuzzy green phase extender functions, which located in different levels of multilevel signal control system. The phase selector is working on the phasing, while the green extender belongs to the green extension level of the multi-level signal control system. The phase selector function determines the next green phase and green extender controller function makes the decision whether to extend or terminate the current green phase. Simulation is used to evaluate the performance of the proposed FSCS system. The FSCS system is compared with pre timed control system and shows significant improvement over pre timed control system. The choice of right of way was basically dependent on the lane with the highest volume of vehicles. The drawback of the work is that the lane with fewer vehicles might be starved for a long time. Vehicular delay was omitted among the fuzzy variables and pedestrian consideration was not path of the work. This is why research is still very necessary towards pedestrian design along with vehicular delay considerations.

Niittymaki and Kikuchi (1998) designed a fuzzy based pedestrian control facility that can be installed in a two lane way. The work used vehicle detectors to determine the volume of vehicle. The variables considered were waiting time of pedestrian, Volume of vehicles and discharge gap. The work did not consider total number of pedestrians and environment variables.

Hassan (2013) proposed an upstream and volumetric pedestrian algorithm for effective traffic time management. The upstream pedestrian detection was placed between 3 – 5metres from the traffic junction. The aim is to prevent delay for pedestrians by signifying the intention to cross using push button before walking to the junction. Sensors were used to determine the total number of pedestrians. The work accomplished more opportunities for pedestrians to cross but incurred greater delay for vehicles. The signal control is also connected with pedestrian walking speed which can be unstable. Pedestrian can push button 5meters away and turn a different direction. Therefore a better system is still required to intelligently manage the traffic without incurring avoidable stops and delay for vehicles.

Yulianto and Setiono (2012) described the design and evaluation of an adaptive traffic signal controller based on fuzzy logic for an isolated four-way intersection with specific reference to traffic in developing countries. The controller is designed to be responsive to real-time traffic demands. Video image processing has been proposed to capture traffic data such as maximum queue length (in metres) and average occupancy rate from each approach of the intersection. The FLTSC uses maximum queue lengths and average occupancy rates collected during the previous cycle in order to estimate the number of seconds of green time required by each set of signal groups (stage) during the next cycle. The drawback of this design is that traffic volumes can vary considerably within a short time. Using previous signal circle time to estimate the next signal stage will not produce optimal results in a dynamic traffic environment.

Sharma *et al*. (2010) developed an adaptive fuzzy logic signal based controller for an isolated four-way intersection that consist of signal analysis at induction sensors, field equipment supervision, incident detection with traffic flow analysis, weather condition detection, and intelligent speed limit control. The system generates congestion information and warning information with suggested actions. The research was congestion focused without consideration for pedestrian right of way.

Koukol and Přibyl (2013) demonstrated that PTV VISSIM can also be used for the evaluation of advanced control algorithms, even without the use of API. That is without the knowledge of classic programming languages such as C ++ or Java. The fuzzy control algorithm was implemented directly in the micro simulation tool and its effect on traffic evaluated. The result indicates 35.59% improvement of fuzzy inference system over fixed time control. The research affirms the use of VISSIM as effective simulator.

Salehi *et al.* (2014) presented an application of fuzzy logic for multi-agent based autonomous traffic lights control system using wireless sensors to overcome problems like congestion, accidents, speed, and traffic irregularity. The real time parameters such as traffic density and queue length are obtained by using image-processing techniques. Thus, on and off timings for the green, red and or amber lights are adjusted to the actual road conditions. The agent-based approach reduced the vehicles' waiting time especially the emergency vehicles using fuzzy logic control under the situations that normally occur during emergencies. Pedestrian traffic and environmental variables were not considered.

Alam and Pandey (2014) designed an intelligent traffic light control system based on congestion estimation using fuzzy logic. The number of vehicles in each lane was determined using sensors. The time allocated to each phase is determined by estimated traffic situation. For the traffic light control, there are four membership functions for each of the three inputs as well as output fuzzy variable of the system. The fuzzy input variables are Vehicle-Arrival, Queue Length, and Right-Queue and output variable Extension time of the system. The flow diagram of a fuzzy logic controller is shown in Figure 2.10. The assumptions of this work includes the following: The junction is an isolated T-junction or 3 way intersections with traffic coming from all the sides, left movement of each lane is always free. When traffic moves from one direction other two directions traffic will remain stop. The fuzzy logic controller will observe the density of all the sides.

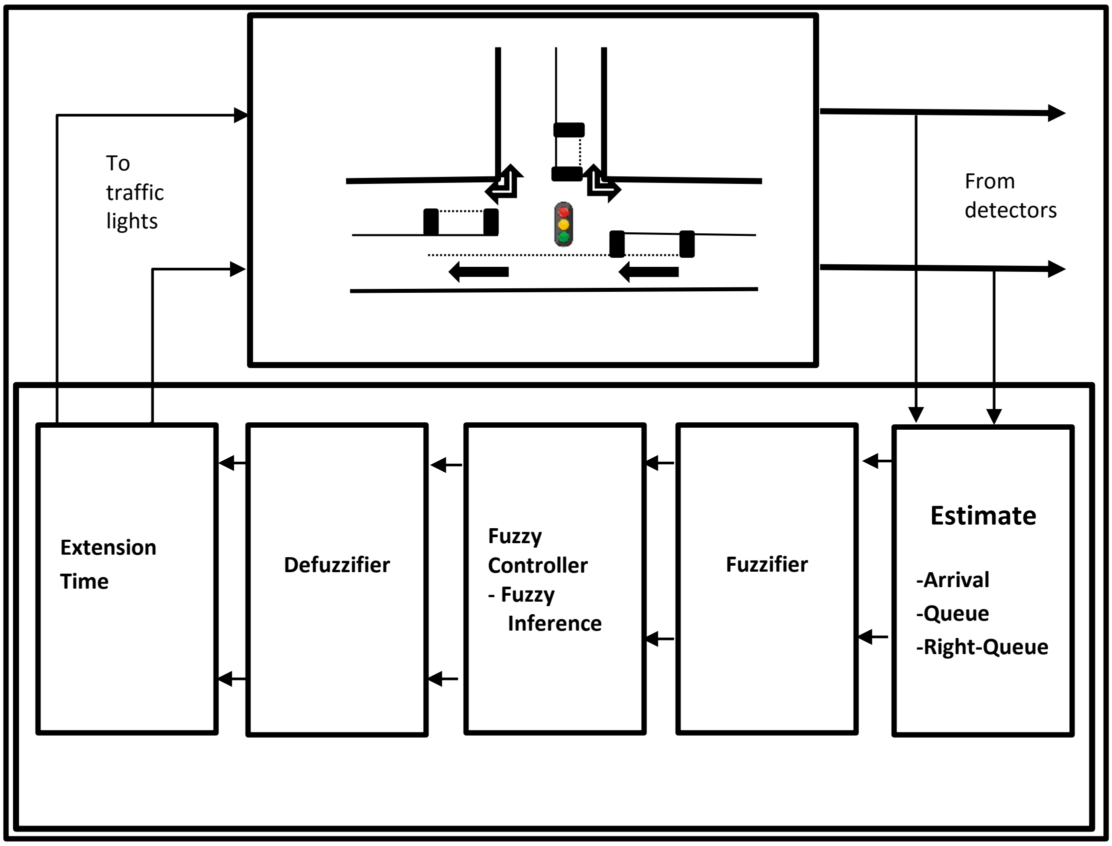


Figure 2.10: Fuzzy logic design for the traffic control (Alam and Pandey, 2014)

The simulation results indicated that intelligent traffic light system (ITLS) has the potential to improve operations at T-junction. It also shows that it can reduce the traffic congestion and avoids the time being wasted by a green light on an empty road. The limitations that need further research are, it is assumed that arrival, queue and right queue lengths can be observed accurately, and there are no pedestrian considerations. To apply the proposed ITLS method in the real world, it is necessary to conduct future studies that take pedestrians into account. More input variables like weather conditions and other environment conditions can be added to have more précised traffic control. Also Very Important Person (VIP) movement was not considered in the ITLS.

Putting into consideration, pedestrian right of way, pedestrian safety parameters and weather variable will be a useful enhancement of this research.

2.7 Pedestrian Safety Evaluation Parameters

NZ (2015) guidelines highlight the factors for seeking improved pedestrian facilities as defect in any or combination of the following Traffic Evaluation Parameters

a. Level of service(LOS)- pedestrian waiting time

b. Pedestrian Crossing time

c. Crash rate

d. Vehicular delay

2.7.1 Pedestrian Waiting Time

This is also known as pedestrian delay or Level of service for pedestrian facility is the average time a pedestrian or group of pedestrians must wait until a sufficiently large gap is available or the pedestrian facilities allowed the waiting pedestrians to cross the road. It can also be referred to as the concept for analyzing convenience for pedestrian traffic along the road (Chertock *et al.,* 2014). Prolonged waiting time instigate misbehaviours at crosswalks. The levels of misbehavior are higher if the waiting time is longer (Table 2.3)

Table 2.3: Average Pedestrian Delay and Risk taking behaviour of Pedestrians at Unsignalized intersections (NZ, 2015)

LOS	Average Delay/Pedestrian (s)	Likelihood of Risk-Taking Behaviour
A	< 5	Lowest
B	≥ 5-10	Low
C	> 10-20	Moderate
D	> 20-30	Fair
E	> 30-45	High
F	> 45	Very High

The model of pedestrian crossing time (t_{cp}) is depicted in NZ (2015) as

$t_{cp} = (d_c/v_w)F_s+C$;   Equation (2.3)

where dc = Crossing distance (m);

v_{w} = mean walk speed (m/s)

F_s = factor of safety (adjust for possible distance related error0

C = confirmation time;

The pedestrian crossing time is a function of the crossing distance and the mean pedestrian walking speed.

2.7.2 Pedestrian Walking Speed on Road Crossing

Speed is a very important measuring parameter for all modes of transportation. Pedestrian walking speed is one of the major issues in the design and optimization of pedestrian facilities. Pedestrian desired speed is the speed with which a pedestrian would walk when pedestrian densities are low and the presence of other pedestrians do not have any effect on them. This desired speed varies according to a range of factors, including age, gender, trip purpose, group size and weather. Individual pedestrians have been shown to cross a street at mid-block locations at higher speeds than in groups depending on group size. Gates *et al.* 2006 compiled pedestrian's average walking speeds from other research work as stated in Table 2.4. The maximum speed for adult is 5.51km/h

Table 2.4: Pedestrian walking speed compiled by Gates *et al*. (2006).

Pedestrian speeds at road crossing for adults and elderly

Study	Mean Speed (km/h)			
	Adults		Elderly (over 65 years old)	
	Men	Women	Men	Women
Coffin and Morrall (1995)	-	-	4.65*	4.46*
Wigan (1995)	4.3 – 6.0	3.5 – 5.8	3.6	2.8
Knoblauch *et al*. (1996)	5.26		4.32	
Fruin(Transportation Research Board, 2000)	3.0 – 7.0			
Willis *et al*. (2004)	4.97 – 5.51		4.18	
Gates *et al*.(2006)	5.29	5.04	4.18	

*over 60 years old

2.7.3 Crash Rate

Crash rates can be an effective tool to measure the relative safety at a particular location. The calculation of crash frequency (crashes per year) divided by vehicle exposure (traffic volumes, or roadway length) results in a crash rate. Crash rate analysis can be a useful tool to determine how a specific roadway or segment compares to an average roadway on the network. A count of the number of crashes is often inadequate when comparing multiple roadways of varying lengths and/or traffic volume. Crash rate is often used to prioritize locations for safety improvements when working with limited budgets and trying to achieve the greatest safety benefits with limited resources. (Clifton *et al.,* 2009; Hunter *et al.,* 2009). For example, it is possible that two roadways in a jurisdiction (Route A and Route B) each have the same number of crashes. However, Route A could have more than double the number of vehicles on a typical day than does Route B. To effectively compare the relative safety of the two locations, the practitioner must factor in the level of exposure on each route. Exposure is often represented by number of vehicles using the route or by the length of the roadway. (Alluri *et al*., 2015).

According to Gates *et al.* (2006), one limitation of crash rates for low volume roads is the sensitivity of the formula to low traffic volume. The crash rate calculation is not as beneficial at low volumes as it is with higher volume roads, as small changes in the number of vehicles results in a disproportionate change in the crash rate for the segments that in reality operate similarly.

Where traffic volume data is unavailable, other information can be used to provide exposure information. One often-used factor is the length of the roadway segment on each route studied.

2.7.4 Road Traffic Entities

Road Traffic systems encompass the interactions of road facilities, flow entities (pedestrians and vehicles) and associated control system. Each of these entities has characteristics that can affect their interactions negatively or positively. Various characteristics of these entities identified through literature (Aworemi *et al.,* 2010, Chen *et al.,* 2012) are listed in Table 2.5.

Table 2.5: List of traffic entities and their characteristics (HCM, 2000; Adaramola and Oyewola, 2011)

Road Characteristics	Vehicle Characteristics	Pedestrian Characteristics	Drivers	Environmental Characteristics
Number of lanes land use Location Urban/Rural) Types of Intersection Speed Limit	Types of vehicles Max Speed Actual speed acceleration, Purpose(public or private), Driver behavior, Energy Consumption, Accelerating power, Vehicle length, Actual position in the network	Age, sex, age, walking speed, weight, behaviour	Psycho-physical perception, threshold-estimative ability, perception of security/safety, willingness to take risk, memory, Driver's desired speed.	Rain, harmatan, heat, wind, dust

For the purpose of this work, pedestrian characteristics (volume, delay), Vehicular Characteristics (Queue length) and weather variable (rain) that have been identified from related literature on safety to have direct influence on pedestrian safety shall be considered (Agarwal, 2011; NZ, 2015; Mead *et al.,* 2014)

2.8 Modeling and Simulation

A simulation is the imitation of the operation of a real-world process or system over time. Whether done analytically or using a computer software, simulation involves the generation of an artificial behaviour of a system and the observation of that artificial behaviour to draw inferences concerning the operating characteristics of the real system (Banks *et al.,* 2013).

The behavior of a system as it evolves over time is studied by developing a simulation model. This model usually takes the form of a set of assumptions concerning the operation of a given system. These assumptions are expressed in mathematical, logical, and symbolic relationships between the entities, or objects of interest, of the system. Once developed and validated, a model can be used to investigate a wide variety of "what if" questions about the real-world system. Potential changes to the system can first be simulated, in order to predict their impact on system performance. Simulation is mostly used to study systems in the design stage, before such systems are built to prevent wastage of resources. Thus, simulation modeling can be used both as an analysis tool for predicting the effect of changes to existing systems and as a design tool to predict the performance of new systems under varying sets of circumstances.(Osigwe *et al.,* 2011).

Models can be defined as the use of symbolic notation and mathematical equations to represent a system. A model constructs a conceptual framework that describes a system. The behavior of a system that evolves over time is studied by developing a simulation model.

2.8.1 Modeling and Simulation of Transportation System

Traffic simulation or the simulation of transportation systems is the act of logical, statistical or mathematical modeling of transportation systems (for example: urban road network, freeway junctions, arterial routes, roundabouts or downtown grid systems). It is often time done through the application of computer software, and it assist in planning, designing and operation of transportation systems. Simulation has become important in traffic engineering and .transportation planning. Various transportation agencies, academic institutions and consulting firms use simulation to aid in the management of transportation networks (Sokolowski and Banks, 2009)

Simulation in transportation is important because it can study models too complicated for analytical or numerical treatment. It is relevance in experimental studies can detailed out relations that might be lost in analytical or numerical treatment and can produce attractive visual demonstrations of present and future scenarios. Scenarios management is another powerful tool for comparing and evaluation of several instances of road networks without material cost.

2.9 Traffic Management Simulators

Traffic simulation is an indispensable instrument for transport planners and traffic engineers. Microscopic modeling of traffic flows is a technique based on the detail description of the characteristics of each individual pedestrian and vehicle composing the traffic stream. This implies modeling the actions – e.g., acceleration, decelerations, and lane changes of vehicles as well as detail vehicle characteristics, driver behavior and pedestrians (Papacostas and Prevedouros, 2008). Microscopic approaches are represented by VerkehrInStädten-SIMulationsmodell (VISSIM) German for “Traffic in cities - simulation model”, Advanced &

Visual Evaluator for road Network in Urban areas (AVENUE), Microscopic traffic simulator (MITSIM) Paramics and Aimsun. A Mesoscopic approach is hybrid in that it comprises of both microscopic and macroscopic techniques in some instances. Examples of hybrid are dynamic traffic simulators Dynameq and Dynamit. Macroscopic simulators treat entities as whole without detailing out the embedded characteristics of the entities (e.g. vehicle). Metanet is representative of macroscopic traffic modeling. (Kotusevski and Hawick, 2009)

Four of these simulators are reviewed briefly; VISSIM is the choice simulator for this research because it is modular in design and this makes it easier to troubleshoot. User define function can be built to replace existing ones where necessary, it can build a large road network as large as a whole city (Robaldo, 2012). Details of traffic entities (pedestrians, and vehicles) can be captured for further analysis). It is also most popularly used in research work because it can be interfaced with other software (Edmar and Hultman, 2014; Alenxander and Johansson, 2013)

2.9.1 VISSIM

VISSIM ("VerkehrInStädten- SIMulationsmodell") is a microscopic, behavior-based multi-purpose traffic simulation that can be used to analyze and optimize traffic flows. It offers a wide variety of urban and highway applications, integrating public and private transportation. Complex traffic conditions are visualized in high level of detail supported by realistic traffic models (PTV, 2011). It is a discrete traffic simulation system modeling motorway traffic as well as urban traffic operations. The position of each vehicle is recalculated every one simulation seconds (Zlatkovic, 2012; Schroeder and Rouphail, 2010)

The software allows for analysis of conditions of traffic in consideration of such conditions as configuration of lanes, structure of traffic types, traffic light systems and public transportation stops. Also, it provides a useful tool for assessment of different alternative solutions used for the measures of effectiveness. It is based on psychophysical model of driver's behaviour developed by WIEDEMANN in 1974 (StanNiek, 2011).

VISSIM has been used for development, assessment and verification of control logic for optimization of traffic flow in road networks as well as analysis of traffic disturbances caused by low speeds and road traffic intersections. An advantage of VISSIM environments lies in facilitated comparison of alternative projects which include the crossroads with traffic lights. This software enables an extensive assortment of urban and highway applications and integrates the public and private transport as well as pedestrians into the model. By incorporating the possibility to simulate different transportation means, PTV VISSIM can replicate complex traffic situations, such as roundabouts and intersections, where numerous conflicts between modes of transport exist (Eidmar and Hultman, 2014; Koukol and Priby, 2013).

VISSIM contains a programming language with a graphical flow charter to define actuated signal control. It is based on structured programming language with added functions relevant for traffic engineers. Furthermore the display of signal groups and stages can be accessed. An actuated logic can be defined based on signal groups or based on stages and inter stages to reflect national standards of signalization.

An interesting aspect is the interaction of pedestrians and vehicles in the simulation. The interaction can be modeled at intersections in the form of signal-controlled or priority-controlled conflict areas.

There are several ways to model signal control in VISSIM:

a. Fixed-time/pre timed signal plans
b. Actuated (via a ring-barrier graphical user interface)

c. User-definable signal control logic through a macro language logic called vehicle actuated programming (VAP)
d. Interfaces to signal controller firmware (virtual controllers) such as Econolite
e. ASC/3 TM SIL or D4
f. Serial communication to external controllers, this enables compatibility with other simulators.

Availability of these features makes VISSIM most suitable for this research.

2.9.2 PARAMICS (PARAllel MICroscopic Simulation)

Paramics is traffic microsimulation software developed by Quadstone. Paramics has a general philosophy of requiring the modeler to create a model of the road network in which drivers move, with a single-minded goal of reaching their destination, as efficiently as possible while obeying the rules of the road and interacting safely with other vehicles in the simulation. It is possible to define where drivers become aware of a junction and hence where they will start to get into the correct lane for their maneuver. Using this mechanism the flow of vehicles in each lane occurs naturally rather than by being prescribed. Each vehicle has a set of basic physical properties such as size and number of sections (for articulated vehicles), maximum speed, acceleration and deceleration. Other parameters are also defined including the demand matrix it will use and the engine type, which governs the quantities of emissions the vehicle will generate. (Kotusevski and Hawick, 2009).

However, Paramics avoids the use of modeling artifacts, even though they may make the task of base model calibration easier. For example it is not possible in Paramics to prescribe, at any point, the proportion of vehicles using each lane on a link.

2.9.3 AVENUE

AVENUE, behavior of pedestrian is normally quite simplified and the impact of pedestrian behavior onto traffic is generally represented as the link capacity reduction. It was designed to evaluate more local traffic management strategies. AVENUE is a hybrid traffic simulation in the sense that the flow model is based on the fluid dynamics but the images of displayed vehicles are discrete. AVENUE is normally applied to a small to middle size network. It has several experiences on impact evaluations of signal control, environmental impact studies, bus transit operations, on-street parking management, road pricing schemes and probe vehicle analyses. The limitation of this simulator is that it cannot be used to model large road network (Kotusevski and Hawick, 2009).

2.10 MATLAB

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. It is multi-components software with many tools and functions to serve a wide range of scientific and engineering research purposes. MATLAB is the official product of MathWorks, it is a proprietary programming language that can be used for matrix manipulations plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran, Python and simulators (MathWorks, 2017)

MATLAB is in automobile active safety systems, interplanetary spacecraft, health monitoring devices and smart power grids. It is used for machine learning, signal processing, image processing, computer vision, communications, computational finance, control design, robotics, and much more. The MATLAB platform was optimized for solving engineering and scientific problems. Built-in graphics make it easy to visualize and gain insights from data. A vast library of prebuilt toolboxes make is easier to get started right away with algorithms essential to researcher's domain. The desktop environment makes experimentation, exploration, and discovery motivating. These MATLAB tools and capabilities were all designed to work together. MATLAB code can be integrated with other languages, enabling users to deploy algorithms and applications within web, enterprise, and production systems. The optional toolboxes include control system designer, control system tuner, fuzzy logic designer, linear system analyzer and neuro-fuzzy designer (MathWorks, 2017).

2.11 Summary of Literatures and Research Gap

From the literatures so far it has been established that the rate of pedestrian/vehicular fatalities are very high and deserves appropriate attention. Researchers have identified lack of adequate pedestrian facilities, human factors (non-compliance drivers, prolong pedestrians delay), considerations for vehicular traffic without corresponding attention to pedestrian traffic among others as major reasons for these fatalities (Hunter *et al.*, 2012; Aworemi *et al.*, 2010). An intelligent pedestrian device has been proposed with recommendation for implementation of the device and a model for estimating pedestrian/vehicular potential conflict has been developed without adequate provision to reduce pedestrian delay as well as vehicle-pedestrian conflict (Armsby 1996). Alam and Pandey (2014) worked on intelligent traffic control to reduce congestion and avoid the time being wasted by a green light on an empty road and recommended that, to apply the proposed ITLS method in the real world, it is necessary to conduct future studies that take pedestrians into account. Therefore the proposed fuzzy logic control system will take into consideration pedestrian right of way, weather variable and the interaction between vehicles and pedestrians to ammonize the conflicting interest of road users to enhance safety.

CHAPTER THREE

DESIGN OF INTELLIGENT TRAFFIC CONTROL SYSTEM

3.1 Introduction

With key findings drawn from the literature review, this chapter therefore presents the proposed intelligent traffic control system. In this chapter, the architecture required to achieve objectives (a) and (b) was developed as well as intelligent fuzzy logic reasoning system with the procedural algorithms. Section 3.1 contains the general methodological flow structure for the research. Section 3.2 discussed the overview of the proposed system, sketch out the pedestrian module, vehicle module and the communication flow between the modules. Underline algorithms to achieve objective (a) were all placed in this Section. Section 3.3 contains the design of fuzzy based intelligent system that features out the interaction between various components. The inference system developed and rules were formulated, thereby achieving objective (b).

3.2. The Methodology

Figure 3.1 is a flow diagram representation of the flow of methods and various procedures followed to achieve objectives of this work. Various literature have been reviewed in chapter two, this is followed by the design of the system and the conceptual view of the model as explained in Section 3.4

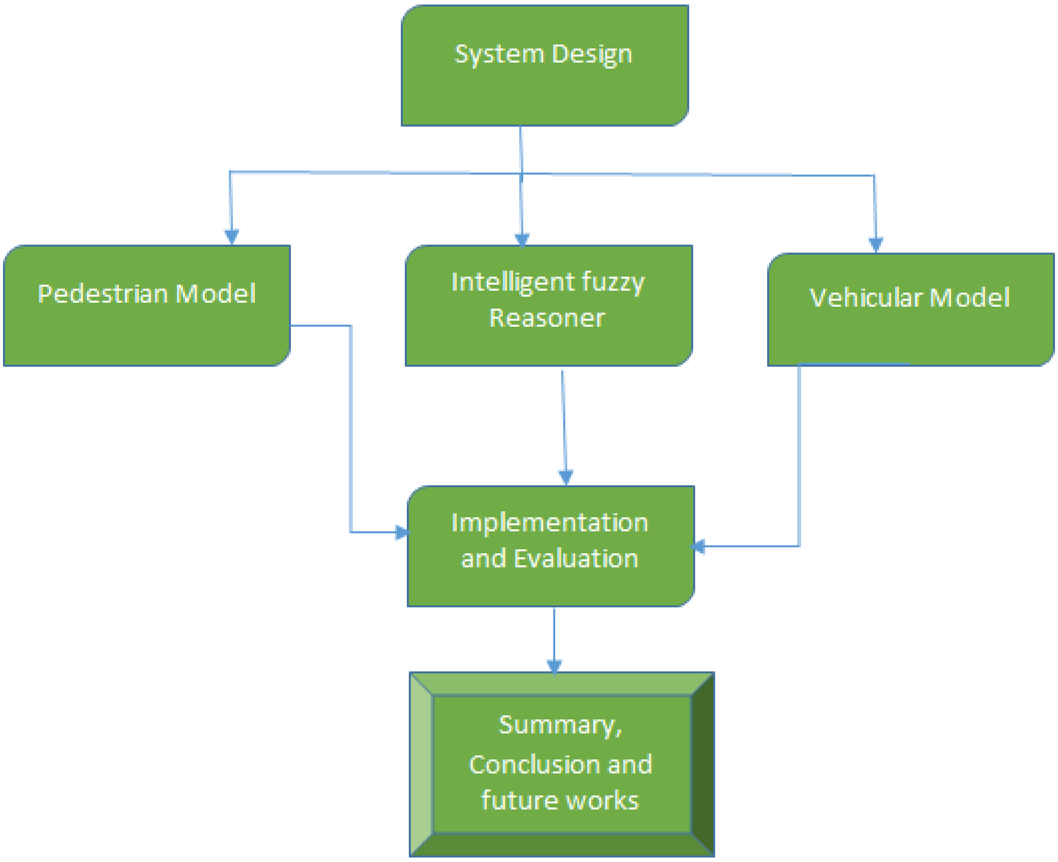


Figure 3.1: The methodological flow diagram of research

3.3 The Overview of the Intelligent Traffic Control System

The general view of the proposed system is represented by the architectural view displayed in Figure 3.2. The vehicular traffic module, pedestrian traffic module and fuzzy logic based reasoner form the major parts of the system. The conceptual view that illustrates the functioning concept of the system is depicted in Figure 3.3.

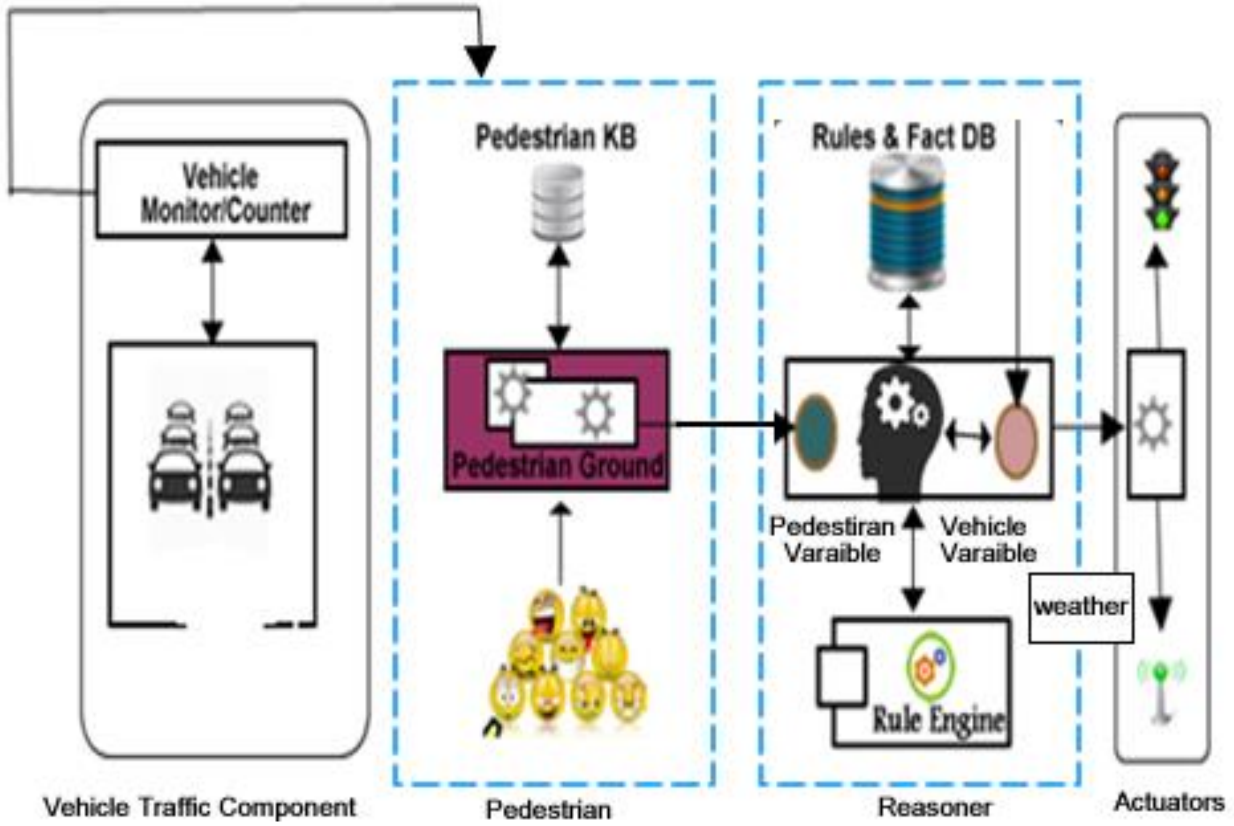


Figure 3.2: Architecture of Intelligent Traffic Control System

3.3.1 Vehicle Traffic Component

Vehicular module comprises of road traffic infrastructures such as road links, vehicle detectors and flow entities such vehicles and bicycles. Detectors can be embedded for vehicle detection and vehicle counts. A four-way intersection with embedded detector was used for the implementation of vehicle environment. Vehicle counts, vehicle time of entrance into the road network and time of departure from the network, as well as vehicle queue length information can be obtained from the road network model using simulation.

3.3.2 Pedestrian Traffic Component

The pedestrian components encompass pedestrian crossing facilities, pedestrian detectors and pedestrian as flow entities. Each of the four vehicle lanes were intercepted by a two way crosswalks. The crosswalks were modeled with embedded sensors for pedestrian movement detection. Pedestrian trajectory data are captured as pedestrians walk from opposite direction.

3.3.3 The Intelligent Reasoner Component

The intelligent reasoner is the harmonizer of the vehicular traffic condition with the pedestrian traffic condition to produce an optimal signal time that is sensitive to the immediate traffic condition. The reasoner was implemented using Fuzzy logic concepts. This module receives crypts values from pedestrian and vehicle modules as inputs into the fuzzy logic inference process.

3.3.4 Actuators

Actuators are devices assigned to each lane on the road network. It receives signal time output from the reasoner and display signal time to give right of way to the flow entities on the lane.

3.4 The Conceptual Framework of the Proposed Intelligent Traffic Control System

The conceptual framework represented in Figure 3.3 is a diagrammatical representation of the flow of information between the different parts of the framework. The algorithms for the implementation of each module represented in the framework are in Section 3.4.1. The DDEM receives inputs from road network as indicated by the arrows, these information are passed to Fuzzy intelligent system. The actual signal time generated by the intelligent system is passed through the DDEM to actuator to control the traffic.

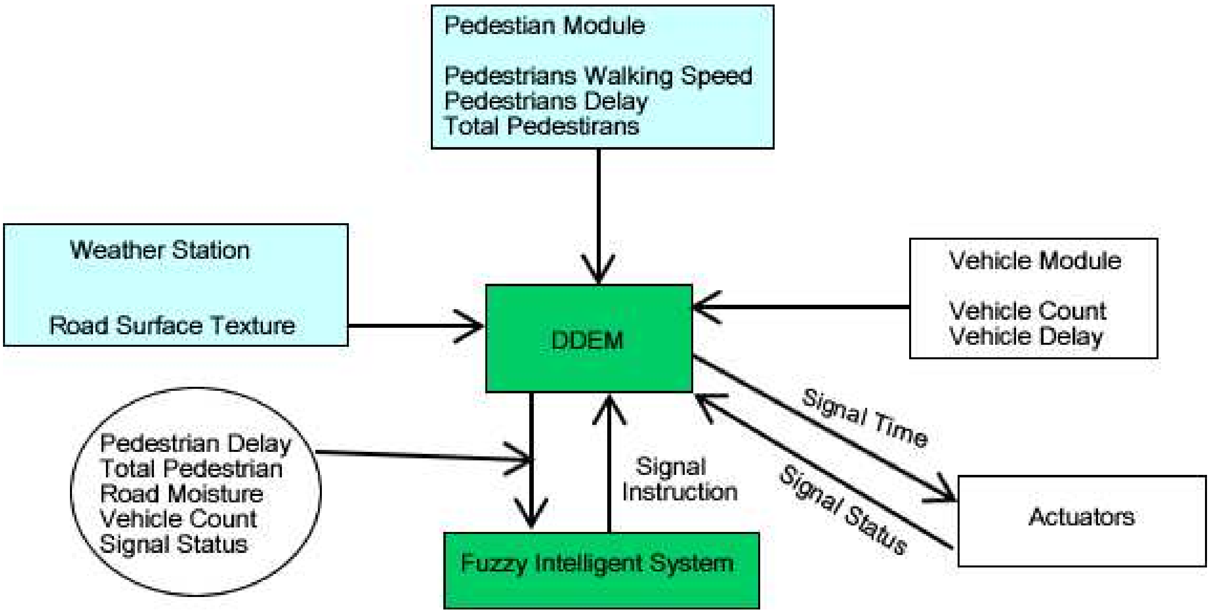


Figure 3.3: Conceptual framework for the proposed pedestrian incorporated intelligent traffic control system

3.4.1 The Algorithms for the various modules

The following algorithms serve the various functional module of the frame work and the flow of information from one module to the other.

Algorithm 1: Four way signal control algorithm

Algorithm 1 encapsulates the operations of the conceptual framework. The road network is a four way network with each road having a signal control head. The signal time sequence of four chances rotating in a loop until the end of the simulation hour set. Each of the lanes has pedestrian crossing on which detectors are placed to detect the presence of pedestrians waiting for right of way to cross. The inputs to the algorithm are vehicle queue length, motor bicycle count and pedestrians volume. All other algorithms are called within the algorithm 1. The output is the signal time which is supplied through the intel_fuzzy_sys for the actuation_algorithm.

```
Algorithm 1 – Four way signal control algorithm
Input: Vehicle_Volume, Pedestrian_Volume, Min_Signal_time
Intermidiary variable: signal_time_countdown, Road_Surface_Moisture
Output: Signal_Time
//System receives Data from pedestrian module and vehicle module, weather algorithms
Foreach lane do
   Call Pedestrian_Module Algorithm
   Call Vehicle_Module Algorithm
   Call Weather_Station Module Algorithm
   If Pedestrian_Volume > 0 // if there is detection of pedestrian input then
    // Evaluate on going traffic situation as follows
      IF Signal_time_countdown >0 AND < Min_Signal_Time THEN
               complete on current green phase until Min_Signal_time
      else // coordination of information flow to reasoner for signal time computation
        Call DDEM_Algorithm (Vehicle_Volume, Pedestrain_Volume, Pede_delay)
     End-IF
  Else {no pedestrian input}
   Vehicle traffic flow continue
  end-if
endfor
```

Algorithm 2: DDEM_ Algorithm

This algorithm controls the flow of information between various components of the framework. It serves as the control unit to collect information and disseminates to various units. The traffic volume inputs information are forwarded to Fuzzy_Intel_Contrl_Syst algorithm to generate the signal time.

1: // Algorithm 2- Dynamic Data Exchange module Algorithm for flow of information within the framework.

2: Algorithm 2 DDEM_Algorithm (Vehicle_Volume, Pedestrain_Volume, Pede_Delay, Road_surface_moisture)

3:   Update files with current evaluation parameters (Vehicles in network, Pedestrian in network, delay file)

4:   Call Fuzzy_Intel_Contrl_Syst *algorithm (Pedestrian_volume, Pedestrian_delay, vehicle_Volume, Road_surface_moisture)*

5:   call signal_actuator Algorithm (Signal_time)

6: return

Algorithm 3 – Signal Actuator Algorithm

This algorithm receives signal time, instruct actuator and send control status to communication module.

1: Algorithm3 – Signal_Actuator (signal_time)

2:   Green_time ← signal_time

3:   Instruct Actuator

4: Return

Algorithm 4: Pedestrian Module Algorithm

This algorithm depicts the operations of pedestrian module, receives pedestrian information from detectors and Computes delays, and then communicates necessary information to DDEM.

```
Algorithm 4: Pedestrian_Module Algorithm
Inputs: pedestrian_volume, pedestrian-arrival_time
For i = 1 to pedestrian_volume
        pede_delay(i) ← present_time – pedestrian arrivaltime(i)
        Total_Pedestrian_delay ←Total_pedestrian_delay + pede_delay(i)
endfor
Average_pede_delay ← Total_pedestrian_delay/pedestrian_volume
Return (Average_pede_delay, pedestrian_volume)
```

Algorithm 5: Vehicle Module Algorithm

This is the vehicle module algorithm, information from vehicle detectors includes vehicle count, vehicle discharge and vehicle delays computations. This information are transferred to DDEM algorithm

```
Algorithm 5 - Vehicular Module Algorithm
    Input: Vehicle_volume
    for  i = 1 to Vehicle_volume
            Veh_delay(i) ←Expected_travel_time(i) – actual_travel_time(i)
            Total_Veh_delay ← Total_Veh_delay + Veh_delay(i)
    endfor
    Average_Veh_delay ←Total_Veh_delay/vehicle_volume
    Return (Average_Veh_delay)
```

Algorithm 6: Weather Station Algorithm

Weather station algorithm received road moisture information from weather detector and transfers same to DDEM for onward communication to Fuzzy reasoner for signal time computations

```
Algorithm 6: Weather_station module
    if detector_value = wet
        Road_surface_moisture ← 1
    else Road_surface_moisture ←0
Return (Road_surface_moisture)
```

Algorithm 7: summarizes the fuzzy inference process. Take input variable from DDEM algorithm, fuzzified the inputs, apply logical operators and evaluate each rule. The inference system aggregates the results of all the rules to obtain a fuzzy output. The fuzzy output is then defuzified using centroid method to obtain crisp output (signal_time)

```
Algorithm 7: Fuzzy_Intel_Contrl_Syst algorithm (Pedestrian_volume, Pedestrian_delay, Vehicle_Volume, Road_surface_moisture)
// Convert crisp input data to fuzzy values using the membership functions
Foreach set of  input parameters do
    MF1←'short':'trimf (input )
    MF2←'medium':'trapmf',(input)
    MF3←'long':'trapmf' (input)
    Apply fuzzy operators (AND)
    Evaluate each rule to get fuzzy output
     Apply aggregation method (max) to results of all the rules (inference)
    //apply defucification (centroid)
     Signal_time ←Centroid (aggregate_fuzzy_value)
Endfor
Return (Signal_time)
```

3.5 Fuzzy Logic Architecture

Fuzzification is the process of changing a real scalar value into a fuzzy value. This is achieved with the different types of fuzzifier's membership function. Figure 3.4 is a functional flow structure of the fuzzy logic system. The system receives pedestrian, vehicular traffic inputs from the traffic simulator for fuzzification, the fuzzified values are passed to inference engine for evaluation using the rule based inference engine, and the resultant fuzzified result is then passed to deffuzifier for conversion to crisp output which can be used to instruct the traffic actuator.

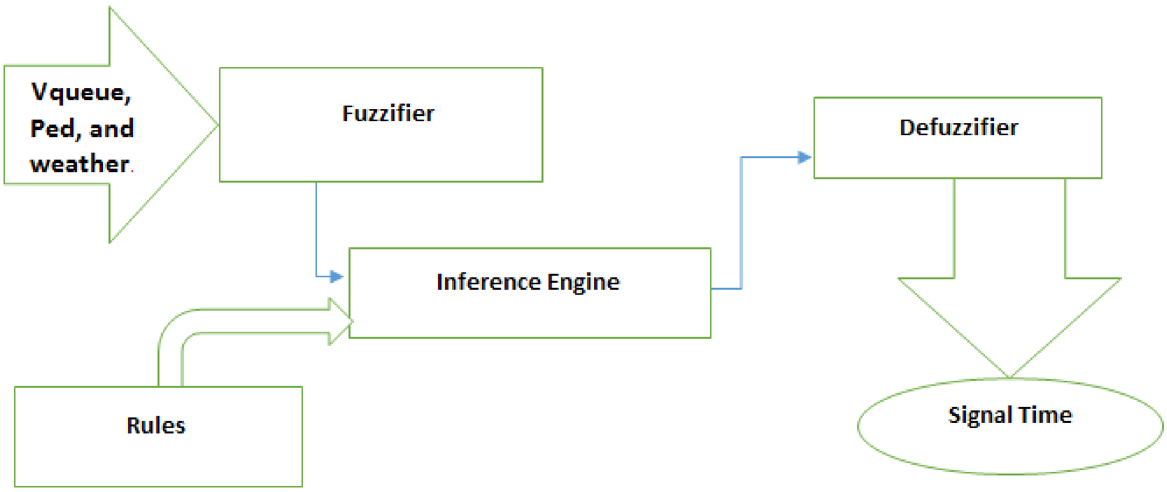


Figure 3.4: The Fuzzy Logic system for the proposed intelligent traffic control

3.5.1 Membership Function

The interaction between pedestrian and vehicles are evaluated using total number of pedestrians, vehicle queue and influence of available environmental parameters. Fuzzy logic system fuzzifies the variable values using linguistic terms according to the membership functions represented in Table 3.1.

Table 3.1: Fuzzy Logic Variables and Linguistic values (summarized from NZ (2015))

Totalped		Peddelay		Vqueue		Weather	
Range	Linguistic value	Range(sec)	Linguistic value	Range	Linguistic value	state	Linguistic value
1 - 42	few	1 – 60	short	1 - 20	Short	0.0 – 0.4	Fair
30 - 100	many	30 – 220	medium	7 - 42	Medium	0.2 - 1	Not fair
75 - 120	Very_many	110 – 300	long	32 - 50	Long		

The output variable membership function is presented in Table 3.2. The linguistic terms were short, medium and large to cover signal ranges from 0 to 60 sec.

Table 3.2: Fuzzified output variable

Signal Command Membership Function(sec)	
short	0 – 30
Medium	10 -50
Large	40 – 60

The plot of membership functions that shows the overlapping linguistic variables are in Figure 3.5(a-d). The triangular and trapezoidal membership functions (mf) were used for the linguistic representations. Triangular functions have three vertexes while trapezoidal has four vertexes. Figure 3.5a is the plot of pedestrian delay membership function. The universe of discourse is peddling (sec) which ranges from 0 to 300 sec. The degree of membership on y axis ranges from 0 to 1. The linguistic terms were short, medium and long. Triangular function was used for short, while trapezoidal was used for medium and long ranges

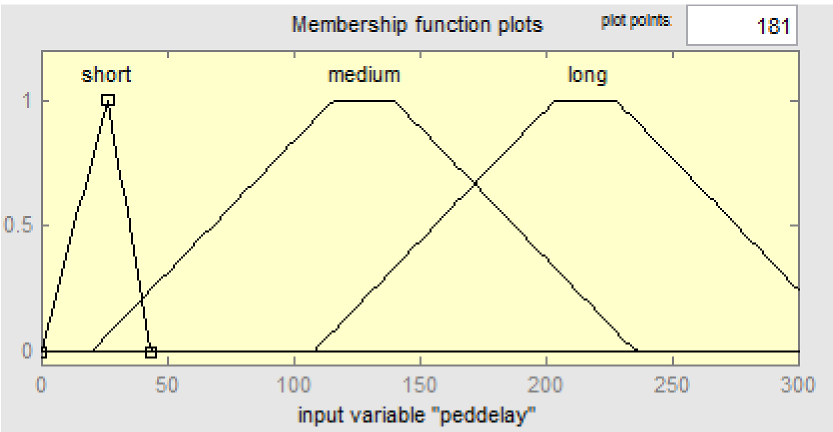


Figure 3.5a: Pedestrian Delay membership function and Linguistic values

Figure 3.5b total pedestrian (totaled) membership function plot. The universe of discourse ranges from 0 to 120 pedestrians. The linguistic terms are few, many and very many. Few as linguistic value has a triangular shape while many and very many has trapezoidal shape. The degree of truth ranges from 0 to 1.

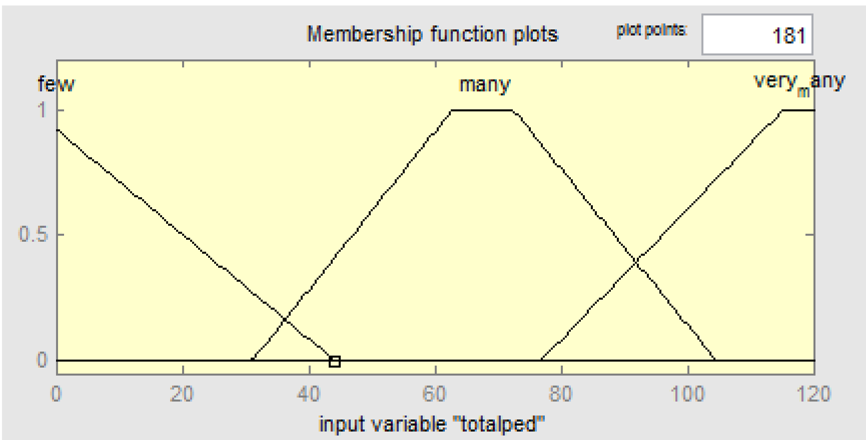


Figure 3. 5b: Total pedestrian membership function and Linguistic values

The third input variable vehicle queue (queue) that is the number of vehicles on the queue is represented in Figure 3.5c. The universe of discourse ranges from 1 to 50. Short, medium and long were the linguistic terms. The y axis represents the degree of truth.

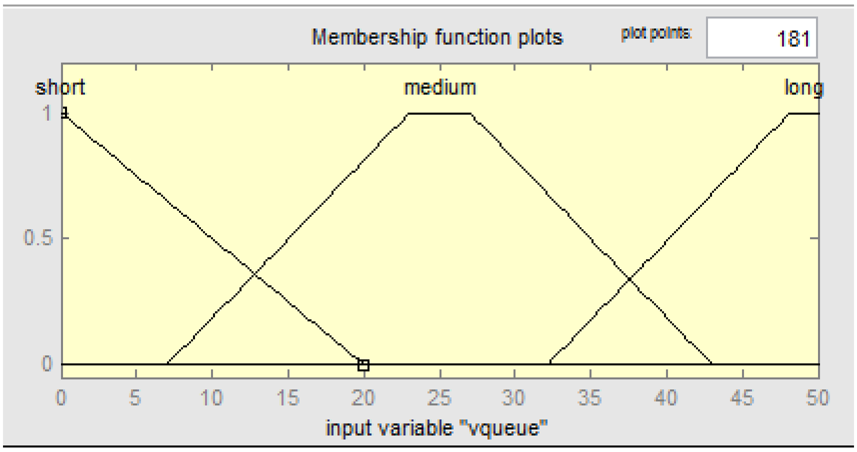


Figure 3.5c: Vehicle queue membership function and Linguistic values

Weather condition as input variable is represented in Figure 3.5d. The universe of discourse ranges from 0 to 1. The linguistic terms are raining and no rain. The linguistic term use triangular shape because of the shortness of the range.

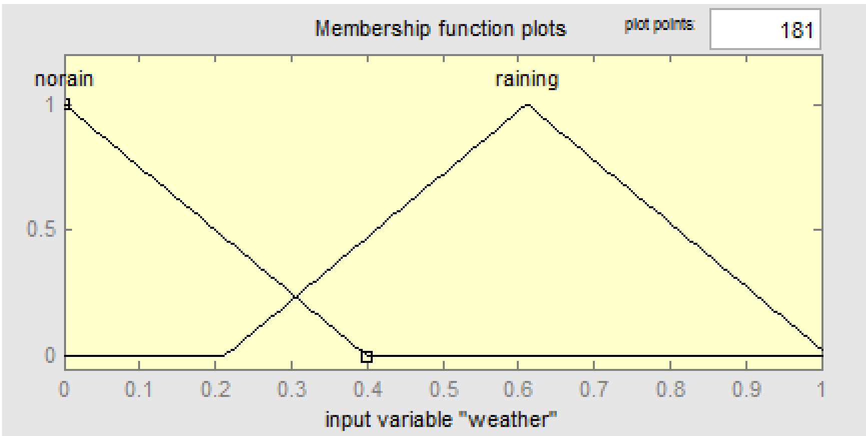


Figure 3.5d: Weather membership function and Linguistic values

The output variable signal time is plotted in Figure 3,5e. The universe of discourse range is from 0 to 60seconds. This means the maximum signal time that can be allocated is 60 seconds. The linguistic terms were short, medium and long.

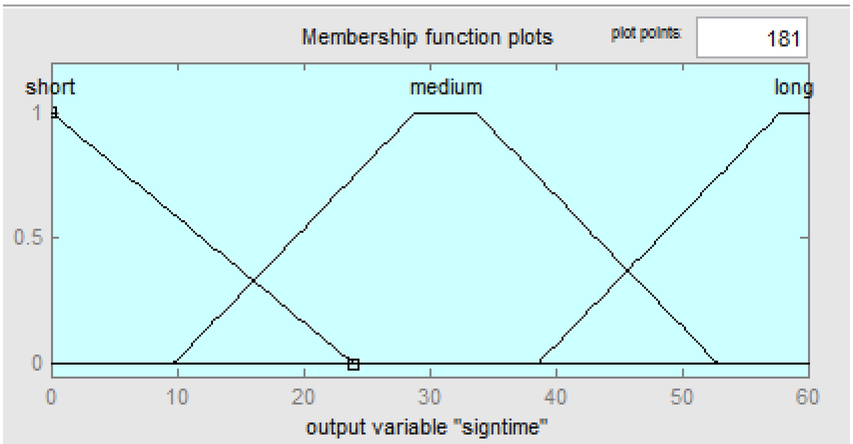


Figure 3.5e: Signal time output membership function and Linguistic values

3.5.2 Fuzzy Rules Formation

Most fuzzy-based systems use production rules to represent the relation among the linguistic variables and to derive actions from the inputs. Production rules consist of a condition (IF-part) and a conclusion (THEN-part). The IF-part can consist of more than one precondition linked together by linguistic conjunctions like AND OR.

To Control the timing of traffic signal intelligently demand evaluation of traffic situation constantly within a defined possible space of time. The total number of rules is the product of the total number of each membership function involved in traffic situation. In this case Queue(3), peddle(3), Totalped(3), weather(2) and sign time(3). The total number of rules was 162 and it is in Appendix M, while a snapshot of the rule formation platform with some of the rules is in Figure 3.6.

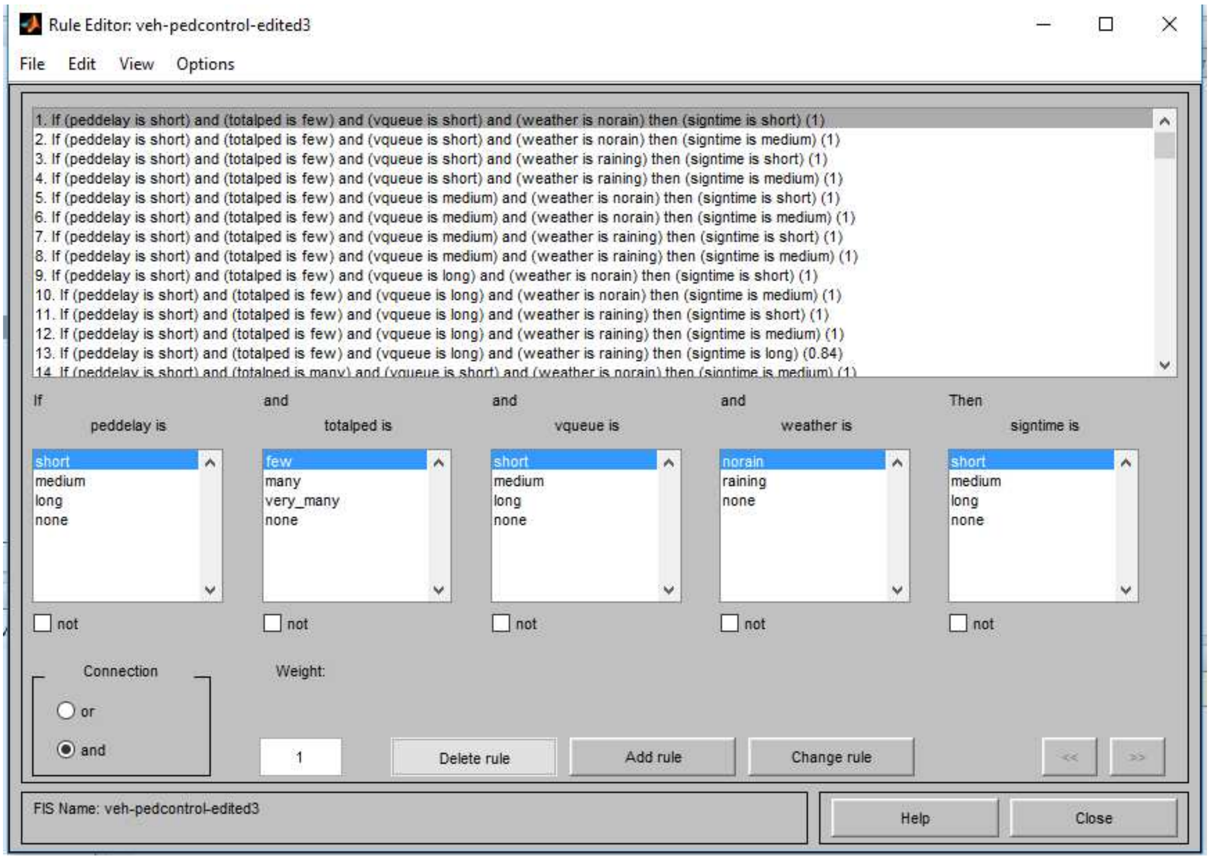


Figure 3.6: Fuzzy Rules

3.5.3 Fuzzy Inference

The first step of fuzzy inference -- aggregation -- determines the degree to which the complete IF-part of the rule is fulfilled. Special fuzzy operators are used to aggregate the degrees of validity of the various preconditions. The computation of fuzzy rules is called fuzzy rule inference. The inference is a calculus consisting of two main steps: aggregation of results of rules and conclusion (deffuzification).

Inference engine examine the rules (if <conditions > then <actions>) execute the actions if the information supplied by the user satisfies the conditions in the rules.

Inference method used for this work is forward chaining. Forward chaining is a top-down method which takes facts as they become available and attempts to draw conclusions (from satisfied conditions in rules) which lead to actions being executed. The algorithm for the inference engine is Algorithm 7. Figure 3.7 is the pictural representation of the inference engine. Totalped, peddelay, vqueue and weather variable are the inputs, while signal time is the output from the inference engine.

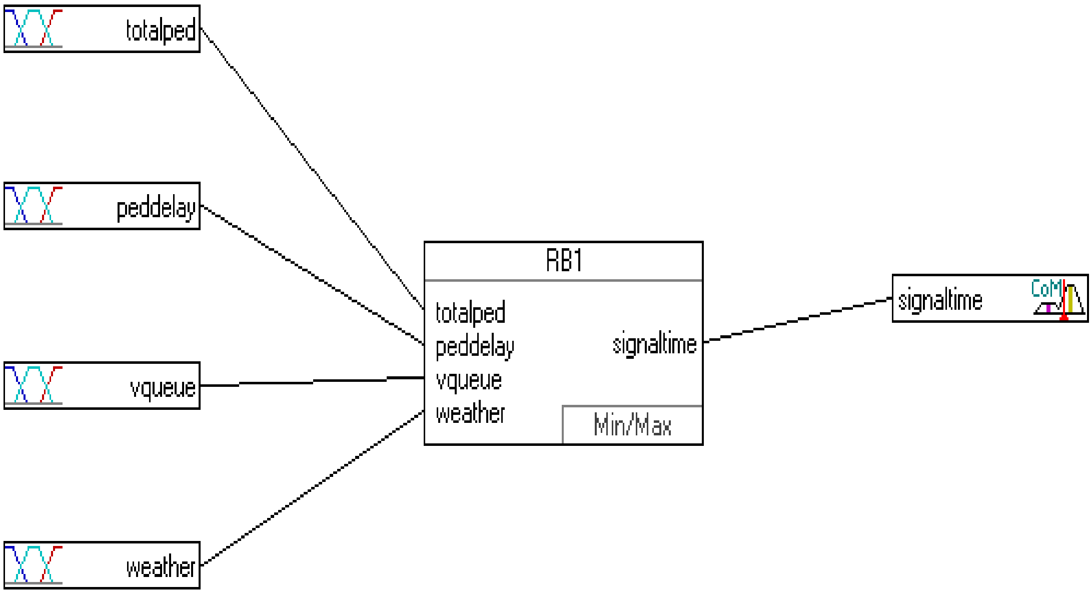


Figure 3.7: Fuzzy Logic inference system

3.5.4. Proposed FITC Fuzzy Inference Model

In modeling this inference system, the centroid de-fuzzification method was used. Let the fuzzy equivalent result corresponding to rule *i* be denoted by y_i.

$$y_i = \text{Max}\left(Min(\mu_{vq(i)}, \mu_{pd(i)}, \mu_{tp(i)}, \mu_{w(i)}),\ \mu_{s(i)}\right) \quad (3.1)$$

Where

y_i – evaluation of rule i

$\mu_{vq(i)}$ – vehicle count membership function for evaluation of rule i

$\mu_{pd(i)}$– pedestrian delay membership function for evaluation of rule i

$\mu_{tp(i)}$ – total pedestrian membership function for evaluation of rule i

$\mu_{w(i)}$ – weather membership function for evaluation of rule i

$\mu_{s(i)}$ - membership function for corresponding output variable

CHAPTER FOUR

ANALYTICAL DELAY ANALYSIS AND NETWORK MODELING

4.1 Introduction

In this chapter, the pedestrian delay was analytically estimated using real life vehicle count from Kano city, Nigeria. The computation was implemented using Java programming language. Fuzzy inference model implemented in MATLAB and signal output generated. Modeling of various road networks and several scenarios management were developed in VISSIM traffic simulator platform

4.2 Estimation of Pedestrian Delay Using Vehicular Count

Having identified the conflicting interest of vehicle drivers and waiting pedestrians on major roads as a threat to pedestrian safety, this section analyzes the impact of increase in Vehicular count on pedestrian delay in Nigeria. Data on vehicular count collected from major roads in Kano, Nigeria were used for this analysis.

For better understanding of the derivation of code implementation of analytical pedestrian delay computations implemented, HCM (2000) models involved in computation of pedestrian delay is stated in Equations (4.1) to (4.7).

$$d_p = \frac{1}{v}\left(e^{vt_G} - vt_G - 1\right) \tag{4.1}$$

where

d_p = average pedestrian delay(s),

v = vehicular flow rate (veh/s), and

t_G = group critical gap (s)

To calculate the group critical gap using the Equation (4.2)

$$t_G = t_c + 2\left(N_p - 1\right) \tag{4.2}$$

where

t_G = group critical gap (s)

t_c = critical gap for a single pedestrian (s), and

N_p = spatial distribution of pedestrians (p).

To calculate the critical gap for a single pedestrian, we use the equation below:

$$t_c = \frac{L}{S_p} + t_s \qquad (4.3)$$

where

t_c = critical gap for a single pedestrian (s),

S_p = average pedestrian walking speed (m/s),

L = crosswalk length (m), and

t_s= pedestrian start-up time and end clearance time (s).

To calculate the spatial distribution of pedestrians, we use the equation below;

$$N_p = INT\left[\frac{0.75(N_c - 1)}{W_E}\right] + 1 \qquad (4.4)$$

where

N_p = spatial distribution of pedestrians (p),

N_c = total number of pedestrians in the crossing platoon (p),

W_E = effective crosswalk width (m), and

0.75m = default clear effective width used by a single pedestrian to avoid interference when passing other pedestrians.

To calculate the total number of pedestrians in the crossing platoon, we use the equation below;

$$N_c = \frac{V_p e^{V_p t_c} + V e^{-V t_c}}{(V_p + V) e^{(V_p - V) t_c}} \qquad (4.5)$$

where

N_c = total number of pedestrians in the crossing platoon (p)

V_p =pedestrian flow rate (p/s),

V = vehicular flow rate (veh/s), and

t_c = single pedestrian critical gap (s).

To calculate the pedestrian flow rate, we use the equation below;

$$V_p = \frac{V_{15}}{15 * W_E} \quad (4.6)$$

where

V_p = pedestrian flow rate (s),

V_{15} = Peak 15-min flow rate (p/15-min), and

W_E = effective crosswalk width (m)

To calculate the effective crosswalk width (m)

$$W_E = W_T - W_0 \quad (4.7)$$

where

W_E = effective crosswalk width (m),

W_T = total walkway width (m), and

W_0 = sum of widths and shy distances from obstructions on the walkway (m).

To calculate the average delay per pedestrian, the followings road complimentary infrastructure standard values were assumed (HCM, 2000). In other words only the vehicular traffic counts (v) were varied across the computation so as to measure the impact of vehicular traffic on pedestrian delay.

t_s = 2sec

S_p = 1.2m/sec W_0 = 0.5m

L = 12m W_T = 2.3m

V_{15} = 25p/15mins

Calculating the effective crosswalk width (m)

$W_E = W_T - W_0$

$W_E = 2.3 - 0.5 = 1.8$m

4.2.1 Code Implementation of Analytical Pedestrian Delay Computation

Java program was developed to compute the pedestrian delay using the unsignalized traffic model in Equation (4.1).

The Algorithm for determining the average delay per pedestrian in a crosswalk

1. Input the values for the following variables:
   a. ts - Pedestrian start-up time and end clearance time
   b. SP - Average pedestrian walking speed (m/s)
   c. W_0 - Sum of widths and shy distances from obstructions on the walkway (m)
   d. L - Crosswalk length (m)
   e. W_T - Total walkway width (m)
   f. V_{15} - Peak 15-min flow rate (p/15-min)
   g. vehicular flow rate per hour
2. Convert the vehicular flow rate per hour (input) to per second (Veh/s)
3. Call the effective crosswalk width (m) function W_E (4.7)
4. Calculate the pedestrian flow rate v_p (4.6)
5. Call the critical gap function- t_c (4.3)
6. Calculate the total number of pedestrians in the crossing platoon N_c (4.5)
7. Call the spatial distribution of pedestrians function N_p (4.4)
8. Calculate the group critical gap t_g (4.2)
9. Calculate the average delay per pedestrian d_p (4.1)
10. Output the average delay per pedestrian in a crosswalk

4.2.2 Results of Computation of Pedestrian Delay from Vehicular Volume.

Table 4.1 is a display of the result of the computation of pedestrian delay against the corresponding vehicular traffic volume. The results indicate increase in pedestrian delay as vehicular volume increases.

Table 4.1 Vehicular count and estimated pedestrian delay (sec)

Veh. Vol. (hr.)	Average Ped. Delay(sec)
557	35.92
603	65.11
629	71.98
642	75.66
665	82.59
670	84.18
672	84.82
703	149.02
789	340.93
825	402.57
853	748.66
866	800.20

The plot of vehicle volume per hour and average pedestrian in seconds is in Figure 4.1. A very sharp increase in pedestrian delay was observed with vehicle volume increment from 100 to 400.

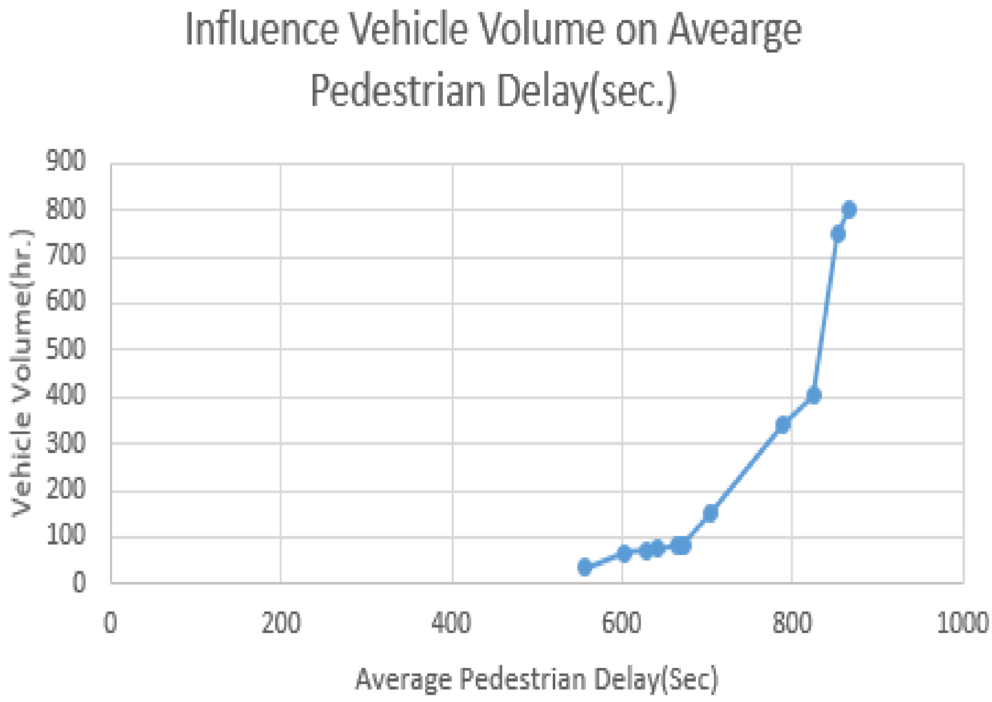


Figure 4.1: Scatter chart used to show relationship between the vehicle count and analytical average pedestrian delay values

4.3 Implementation of Fuzzy Inference System in MATLAB

The inference system implementation includes fuzzification of membership functions, application of fuzzy operators in the antecedent and evaluation of the implication from antecedent to subsequent consequent decision linguistic values. The aggregation of all consequent values according to the rules is then deffuzzified to obtain single signal time output value.

Fuzzification: - Translate inputs into truth values;

Rule Evaluation: - Compute output truth values;

De-Fuzzification: - Translate truth values into output;

In this work, the triangular and trapezoidal membership functions (mf) were used to describe variables. For any given Crisp input (x), the triangular membership function fuzzifies the input using Equation (4.8)

$$f(x) = max\left(min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \quad (4.8)$$

where: a and c are the vertices of the triangle in the x-axis and b is the peak. Similarly, the fuzzification function for trapezoidal membership function could be described using its vertices a, b, c and d as in Equation (4.9)

$$f(x) = max\left(min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \quad (4.9)$$

As an illustration, consider a peddelay of 150s.

a. Let medium be represented by a trapezoidal membership function with: a=19.78, b=115.8, c=138.8 and d=235.8. Similarly substituting these values in equation (4.2) gives

f (150) = 0.8845

b. Let Long be represented by a trapezoidal membership function with: a=107.8, b=203.8, c=227.8 and d=323.9. Similarly substituting these values in equation (4.2) gives *f(150)* = 0.4396

However, f(150) is therefore a medium peddelay value since the medium case has the highest value.

4.3.1 The Inference Model Evaluation Process

In the case of rule evaluation, inputs are applied to a set of if-then control rules and the rule firing strength $y_{w(i)}$ of each of the rules is calculated using AND operator;

Using 'and' operator $y_{w(i)}$can be determined using Equation (4.10).

$$y_{w(i)} = \left(Min(\mu_{vq(i)}, \mu_{pd(i)}, \mu_{tp(i)}, \mu_{w(i)}\right) \quad (4.10)$$

where

$\mu_{vq(i)}$ – vehicle count membership function for evaluation of rule *i*

$\mu_{pd(i)}$– pedestrian delay membership function for evaluation of rule *i*

$\mu_{tp(i)}$ – total pedestrian membership function for evaluation of rule *i*

$\mu_{w(i)}$ – weather membership function for evaluation of rule *i*

i - 1 to 162 (total number of rules)

Using the centroid de-fuzzification method,

Equation (3.1) is the evaluation result of each denoted by y_i.

$$y_i = Max((Min(\mu_{vq(i)}, \mu_{pd(i)}, \mu_{tp(i)}, \mu_{w(i)}), \ \mu_{s(i)})) \tag{3.1}$$

Then for the combine consequences of the outcome of all the rules *ST* is given by Equation (4.11)

$$ST = \frac{\sum_i^m \mu_{y(i)} * y_i}{\sum_i^m \mu_{y(i)}} \tag{4.11}$$

Incorporating equation (3.1) into (4.11) the FITC inference model for ST becomes

$$ST_{FITC} = \frac{\sum_i^m \mu_{y(i)} Max\left(Min\left(\mu_{vq(i)}, \mu_{pd(i)}, \mu_{tp(i)}, \mu_{w(i)}\right) \mu_{s(i)}\right)}{\sum_i^m \mu_{y(i)}} \tag{4.12}$$

where m is 162, i.e. the total number of rules.

The evaluation structure for inference process is represented in Figure 4.2. This structure illustrates evaluation process from Antecedence where inputs are fuzzied using membership functions, to rule formation (162), evaluation of each rules get fuzzified result of each rule.

The aggregation of various rule result gives fuzzified output result. Deffuzification of the fuzzy result gives crisp value as signal time.

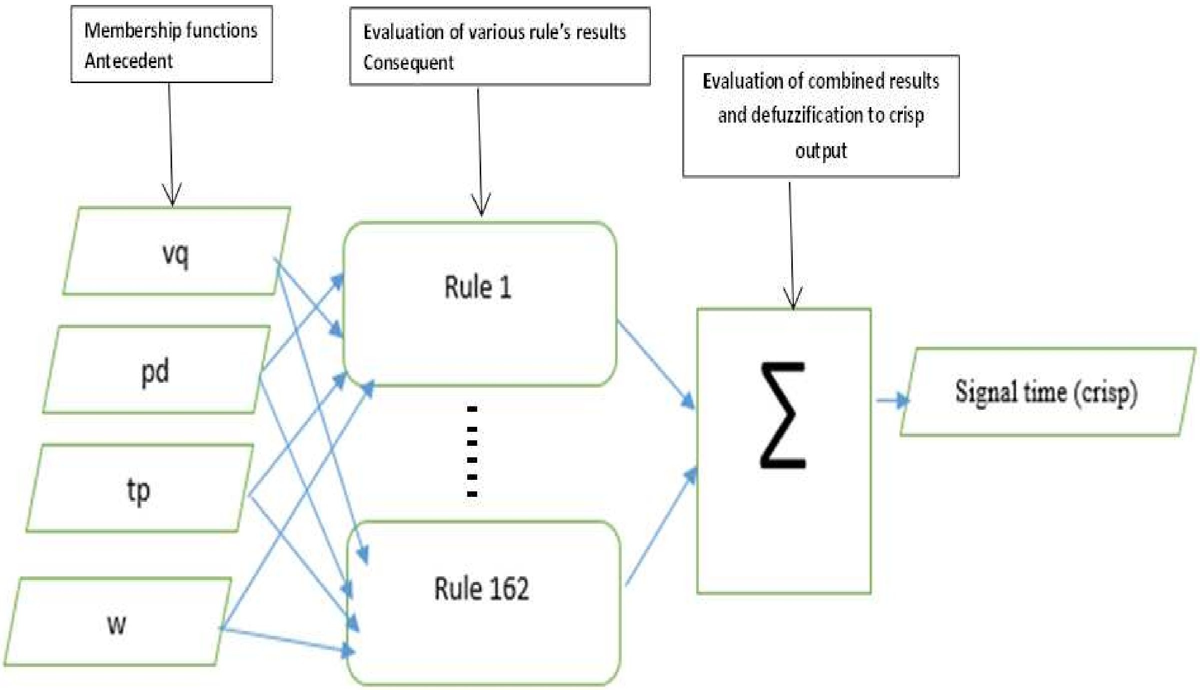
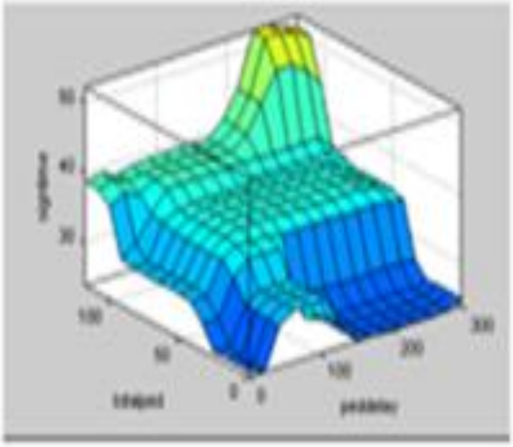


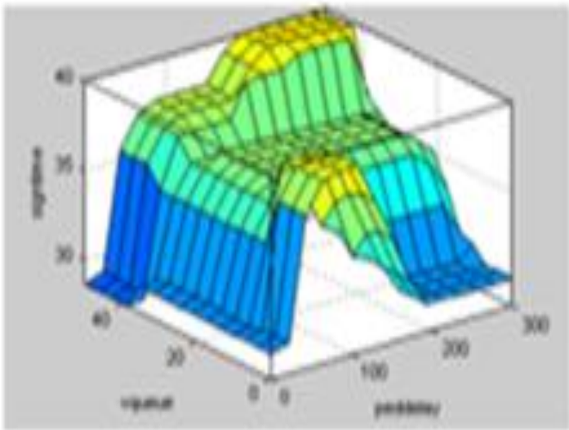
Figure 4.2: Illustration of Inference Process

4.3.2 Input – Output Relationship Plot

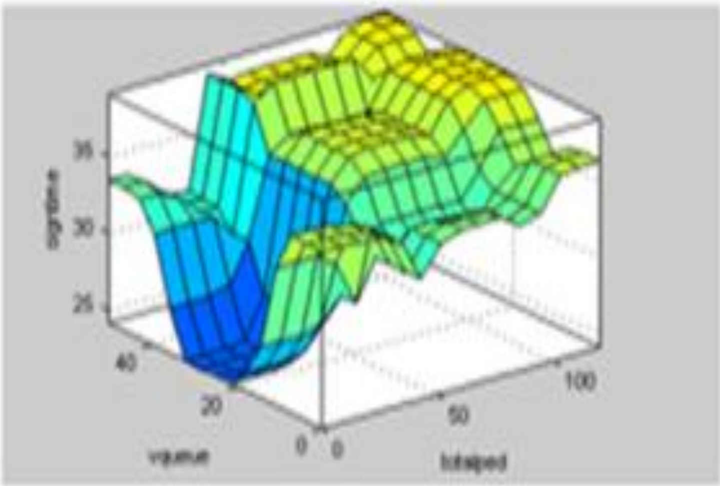
The relationship between two inputs variables plotted against the signal output as in figure 4.3(a- c). The Plot is a three dimensional surface plot, one input variable was kept constant while two others plotted against the generated output. This can be used to trace the signal value given two inputs while the third input is kept constant.



a) Plot of total Ped, peddelay, signaltime



b) Vehqueue, peddelay, signaltime



c) vehqueue, total ped and signaltime

Figure 4.3: Surface View of Output against selected input variables

The rule view indicating input and corresponding output values are represented in figure 4.3. In this view snapped from MATLAB, all the four inputs were displayed in the first four columns. As the input values changes it is reflected in the signal output and this proved the sensitivity of the system to inputs from vehicle and pedestrian traffic. This view carries along the display of all the variables. Other sample inputs with corresponding signal outputs are displayed in Table 4.2.

Figure 4.4: Rule view of inference system

The inference system was tested with sample inputs, the sample signal outputs are displayed in Table 4.2. Figure 4.4 is the plot of the extract of pedestrian delay with signal time output. This displays the impact the pedestrian delay had on signal time.

Table 4.2: Signal Time Output with sample input

Peddelay(sec)	TotalPed	Vqueue	Weather	Signaltime (output)
0	30	25	0.5	30
50	35	25	0.5	30
100	40	25	0.6	33.3
150	30	25	0.5	34
200	30	25	0.4	34.2
250	30	25	0.7	34.2
300	37	25	0.3	34.2
350	30	25	0.5	34.2
400	30	25	0.6	35
450	35	25	0.5	35.7

Figure 4.4 is a plot of signal time allocation against pedestrian delay. Table 4.2 and Figure 4.4 reflect that the input variable actually has impact on signal timing.

Graph of Signal Output against Pedestrian Delay

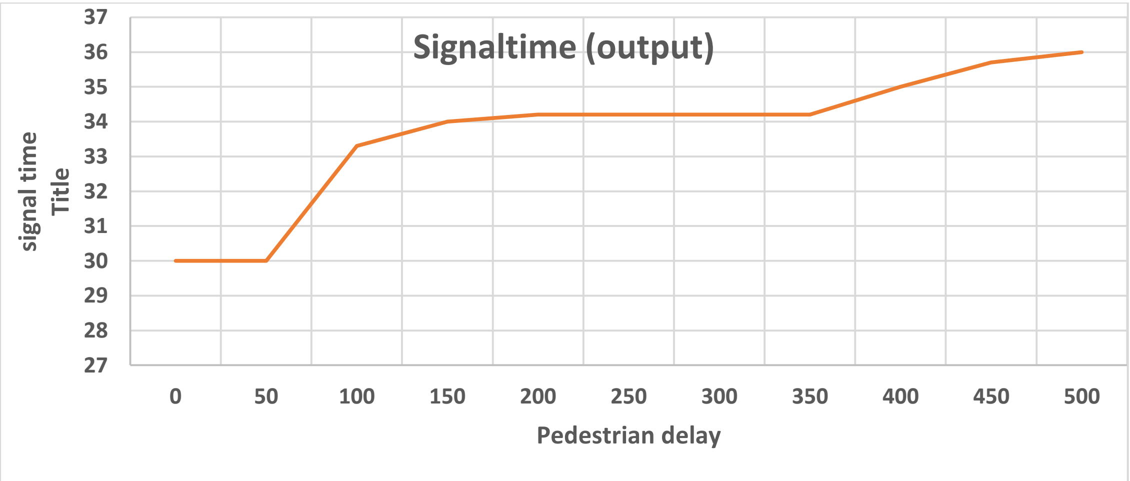


Figure 4.5: Plot of pedestrian delay against signal timing.

4.4 Modeling of Road Traffic Network

VISSIM microscopic traffic network simulator has all the basic modeling tools and graphic features as well as microscopic sensitive background to model the four-way intersection. It can as well gather trajectory data from vehicle-pedestrian interactions for safety analysis.

4.4.1. Basic Modeling Tools

a. Links for roads modeling: links were used to model vehicle or pedestrian lanes. A link can contain one or more lanes on which vehicles and pedestrians move. Link modeling allows the designer to determine various types of traffic flow entities allowed on the links. Links and connectors were used to model the intersections

b. Flow entities: these are the moving objects on the defined links. These are Vehicles, Motor Bike and pedestrians

c. Detectors: detectors are placed on links to record vehicles or pedestrians for vehicle-actuated signal controls. In VISSIM, detectors are modeled as network objects on links for which specific length can be specified.

d. Sensitive backgrounds for trajectory measurement: For the precise modeling of a network, the background must be scaled precisely according to the desired road network. A network coverage of 1000m was used for all the scenarios

e. Scenario management features: Scenario management is used to manage related networks in a single project. The aim is to model comparable cases of road networks and then compare their simulation results. For each case within a project, an instance is created as a separate network and is saved as a scenario. Then the desired evaluations configured and simulation runs for the scenarios whose simulation results are to be compared

f. Signal heads: in VISSIM, signal heads are displayed as red lines by default. Signal heads are placed on links at desired positions. Each signal heads are associated with signal control program.

4.4.2 Procedures for Network Modeling

a. Background Settings: VISSIM has graphical user interface network editor that is used to set up the network. The background scaling to the size of the study area coverage is important to every other modeling step. The trajectory of the data is dependent on the back ground.

b. User Preferences: Most countries have driving style, for instance, Nigeria driven is right handed, this must be considered because it controls the driven behavior in the network

c. Modeling Links and Collectors: Links are the major functions used to model road infrastructure. After the links are created, connectors are necessary to join them together. Just a geometrical overlap of two links does not allow vehicles to travel from one link to another. Here connectors are needed. Hence a typical travel path in VISSIM consists of link – connector – link – connector and so on. Connectors can only be placed on links, not on other connectors.

d. Vehicle Inputs: various vehicles input modeling on the created links

e. Turning Movements: various allowable turning movement modeling.

f. Routing Decisions: Involves setting in place possible decisions at turning points.

g. Routes: all possible movement towards all directions for vehicle movement and travel time measurements.

h. Turning Volumes: What percentage of vehicle volumes are turning and in what direction?

i. Speed Reductions: speed reduction area must be modeled as in real life

j. Right of Way: at every conflicting point, the right of way must be determined either by priority rule, conflict area modeling or signal control.

k. Configuring and coding the simulation and evaluation profiles

l. Simulation runs

4.4.3 Inventory of Model Elements

a. Speed limit

Speed limit is the maximum speed expected of vehicles on the road. Nigeria speed limit for various vehicle types and roadways represented in table 4.3 was used as a guide to set the speed limit for vehicles in the modeled road network.

Table 4.3: Vehicular speed limit in km/hour (Nigeria Highway Code, 2013)

Types of Vehicles	Town and Cities	Highway	Express way
Motorcycles	50	50	-
Private Cars	50	80	100
Taxis and Buses	50	80	90
Tankers and Trailers	45	50	60
Tow vehicles (while towing)	45	45	45
Tow vehicles (while not towing)	50	60	70

For general simulation settings, Table 4.4 captured the speed limit for various types of vehicles in the road network. The Nigeria speed limit setting in Table 4.3 was used as a guide for the speed limit settings.

Table 4.4: Simulation speed limit

Types of vehicles	Max. Speed Distribution
Car	50 km/hr.
Bus	50 km/hr.
HGV	50 km/hr.
Bike	12 km/hr.
Pedestrians	5 km/hr.

b. General Model layout

The major process of model development comprises the network geometry design, lane formation using network links, detectors and stop signs placement and configurations, modeling traffic parameters, placement of routing decisions and reduced speed areas for turn movements, assigning priority for movements in conflict areas and designing signals. Design of pedestrian links as crosswalks and detectors were placed for pedestrian detection. Road network models were developed using typical intersection characteristics along state road in Kano. Intersections were modeled as a minimum length of 500 meters wide for sufficient queue storage.

The built in Wiedemann 99-car following model was used for vehicle behavior, and default driving behavior parameters adopted (Wiedemann, 1999). Pedestrians were modeled as a type of vehicles moving at the maximum speed of 5km per hour. The Crosswalks were modeled to allow pedestrians to follow each other as well as to overtake if required, within the same directional link. The crosswalk comprises of two lanes in opposite direction for up-down movement.

c. Parameter Measurement files

It is very paramount to Traffic modeling, the setting for various data capturing sections and traffic parameter measurement data file so as to gather all necessary information for evaluation purposes. Some of these data files include traffic in network, SSAM *.trj, pedestrians in network, detector readings, network layout file, network delay measurement and signal changes files. Each of these evaluation files are recorded distinctively for each simulation runs.

Table 4.5: Table of sample VISSIM simulation file

File type	Content Description
*.lzv	Distribution of signal time
*.lsa	Signal changes protocols
*.pp	Information on pedestrians in the network
*.rsr	Table of travel time (Appendix K)
*.sig	Signal program/codes (Appendix H)
*.inpo	Pedestrian input
*mer	Data collection file
*.trj	Vehicle/pedestrian trajectory file
*.fhz	Table of vehicle entered containing each vehicle type, number, link, lane, time and speed (Appendix J)
*.fzp	Vehicles in network
*.dis	Discharge record file
*.inpx	Model design file
*.layx	Model layout file(Appendix L)

e. General simulation settings

The purpose of the model is to build a four way intersection with multiple lanes and pedestrian crossing so as to generate various traffic types, create various scenarios based on traffic volumes to measure their interactions and evaluate the management of right of way amidst the road users. It will be of necessity too to gather trajectory data for safety analysis. Traffic Volumes - vehicular volume ranges from 100 to 1000 on each link, at the increment of 100. The vehicle volume was based on average vehicle counts obtained from Federal Road Safety corps in Kano. Pedestrian volumes range from 20 to 120 at the increment of 10 on each pedestrian crosswalk across each link.

Simulation run length is 3600 sec. The volume used is a replica of Kano (Nigeria) traffic count. The simulation speed is set to maximum speed depending on the speed of the processor. The snapshot of this setting is in Figure 4.6.

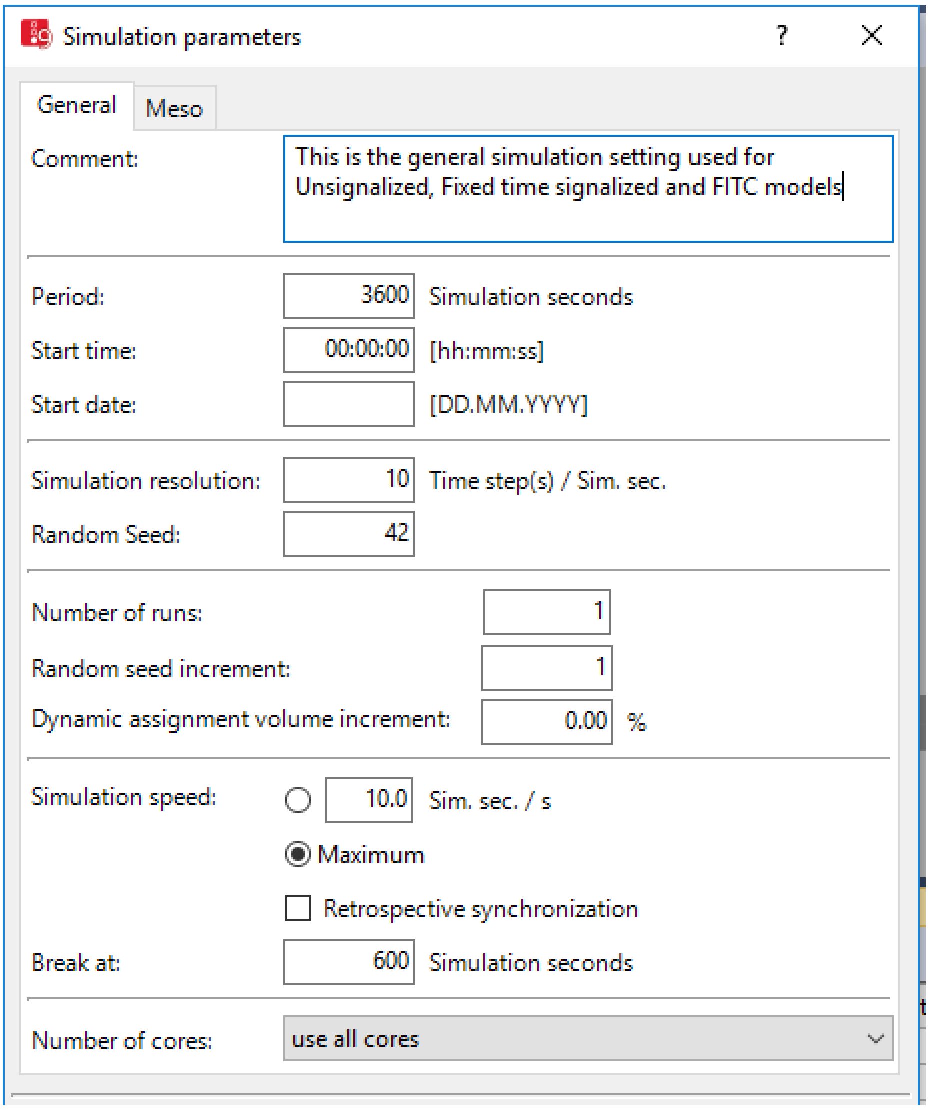


Figure 4.6: General simulation settings

f. Vehicle Types

Vehicle type is used to form a group of vehicles with the same technical driving characteristics. The vehicle type data take part in calculations such as delay, emission and travel time. VISSIM provides the following default vehicle types such as car, bus, HGV, motor bike and pedestrian (modeled as vehicle types)

Different types of vehicles and categories of pedestrians involved in traffic composition with their attributes are indicated in Figure 4.7 – 4.12. The attributes of each of these flow entities are also indicated in the snapshots. These attributes include individual vehicle length, width, colour compositions and unique identification number as well as pedestrian composition comprising of male, female and parents. The summary of these characteristics is in Table 4.6. For each of the traffic entities different types were modeled to reflect the traffic mixed in real life. For instance, man, woman, short man, woman with child is modeled into the network. This is to have varied walking speed in the network. The same mixed composition applied to cars and bike (bike man, bike woman). Relative flow is the Share of the vehicle type in the composition. Figure 4.7 is the display of car as vehicle type, the car length ranges from 3.75m to 4.76m. Default colour types were used for the simulation.

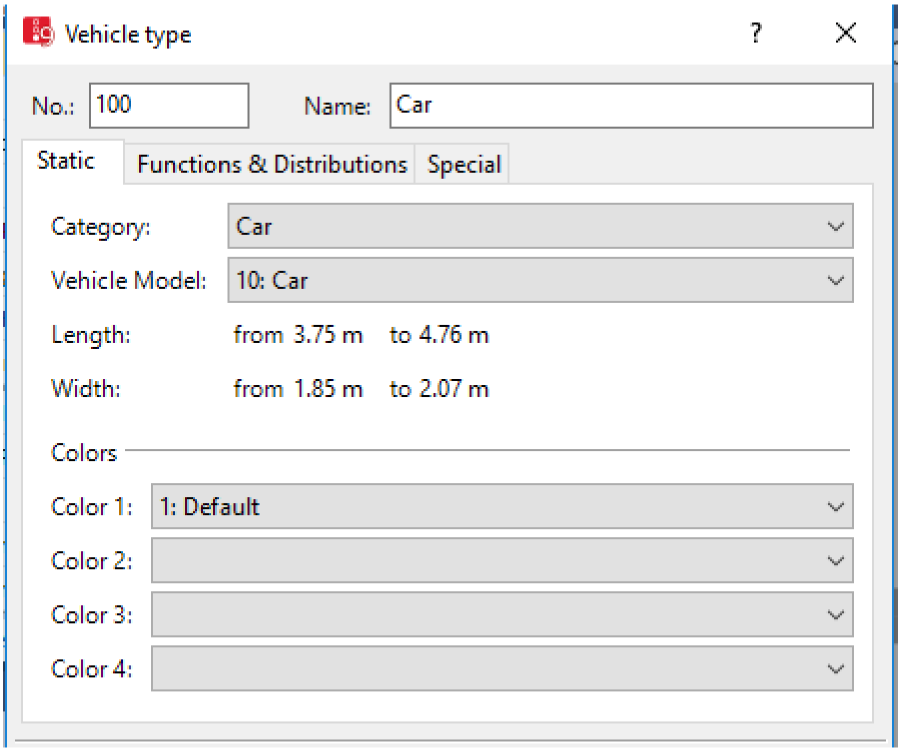


Figure 4.7: Car attributes in the network

HGV as one of the default vehicle type described a group of heavy good vehicles that can be of different model but similar accelerating speed. The vehicle width and length are 2.5m and 10.22m respectively as indicated in Figure 4.8.

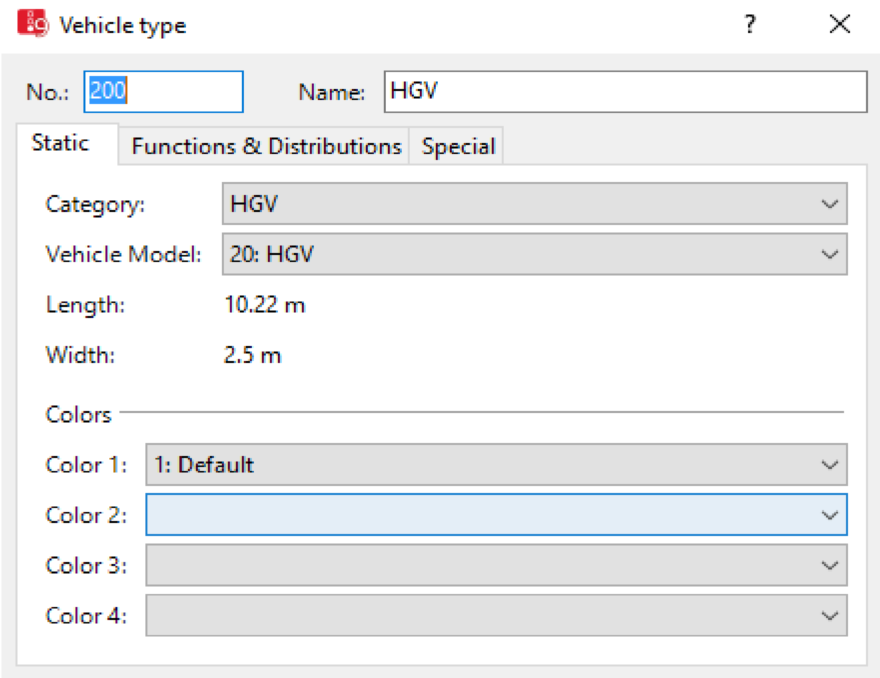


Figure 4.8: Heavy Good Vehicle attributes

Male pedestrians are modeled as vehicle type man. Different human attributes such as length (height), width and the types of cloths are used to represent different types of male pedestrians as indicated in Figure 4.9.

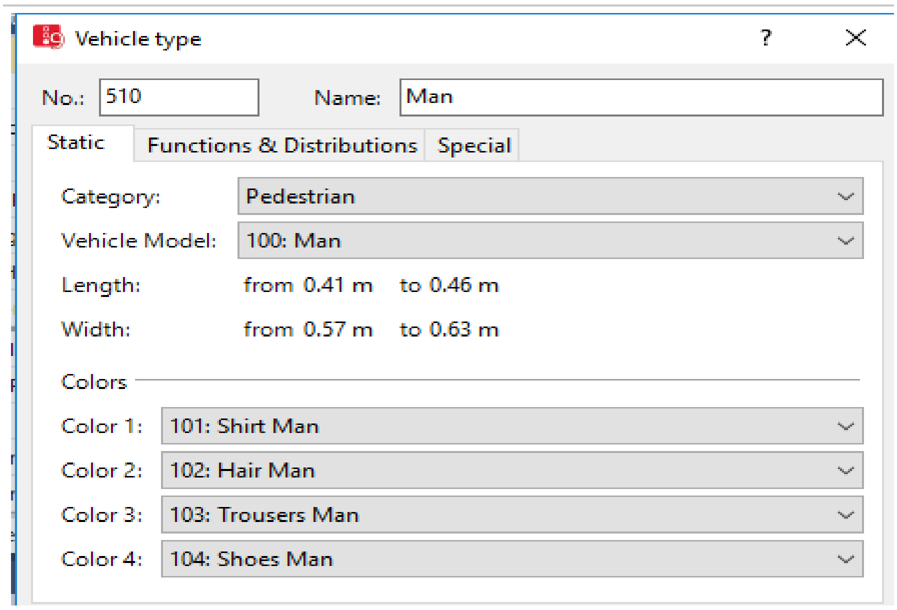


Figure 4.9: Composition of male pedestrians

Female pedestrians are represented as vehicle type. Attributes such as types of cloth and hair were also used to generate different type of women traffic (Figure 4.10)

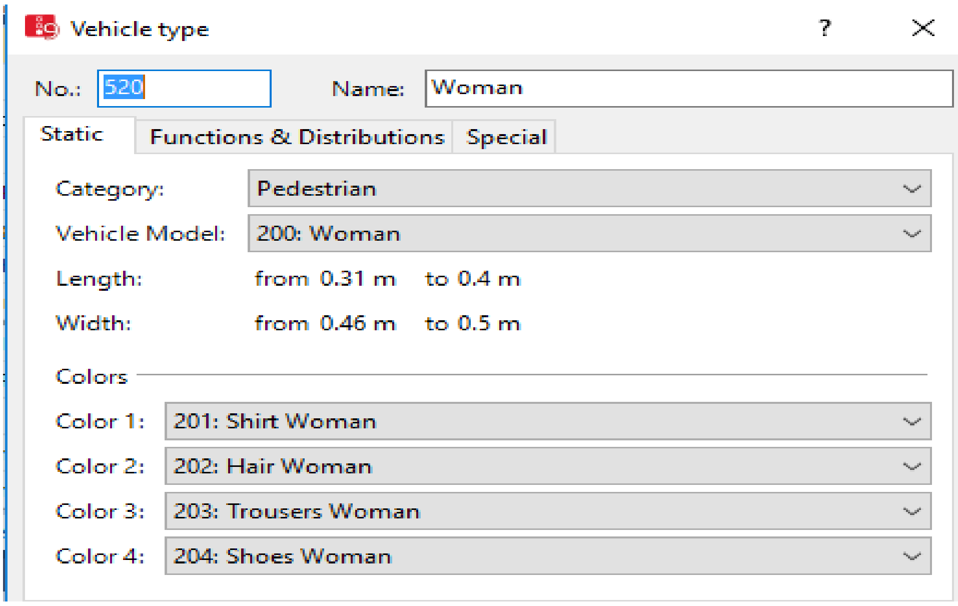


Figure 4.10: Composition of female pedestrians

Bike Man is another vehicle type, the length is 1.77m and width is 0.63m and different height and cloth types were also used to have varieties of Bike man in the network as represented in Figure 4.11.

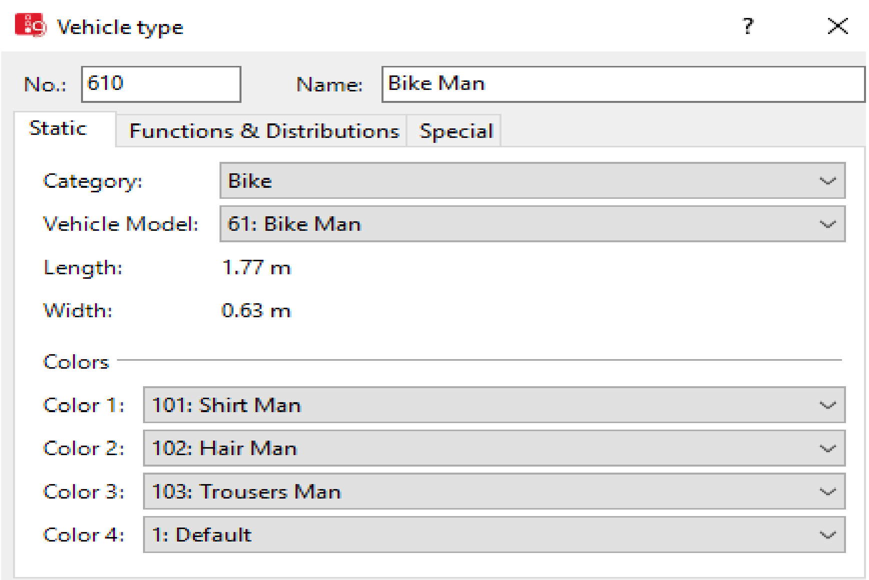


Figure 4.11: Composition of male Bike Man

Female Bike rider was modeled as Bike woman. The length of the Bike is 1.77m and width 0.66m as represented in Figure 4.12.

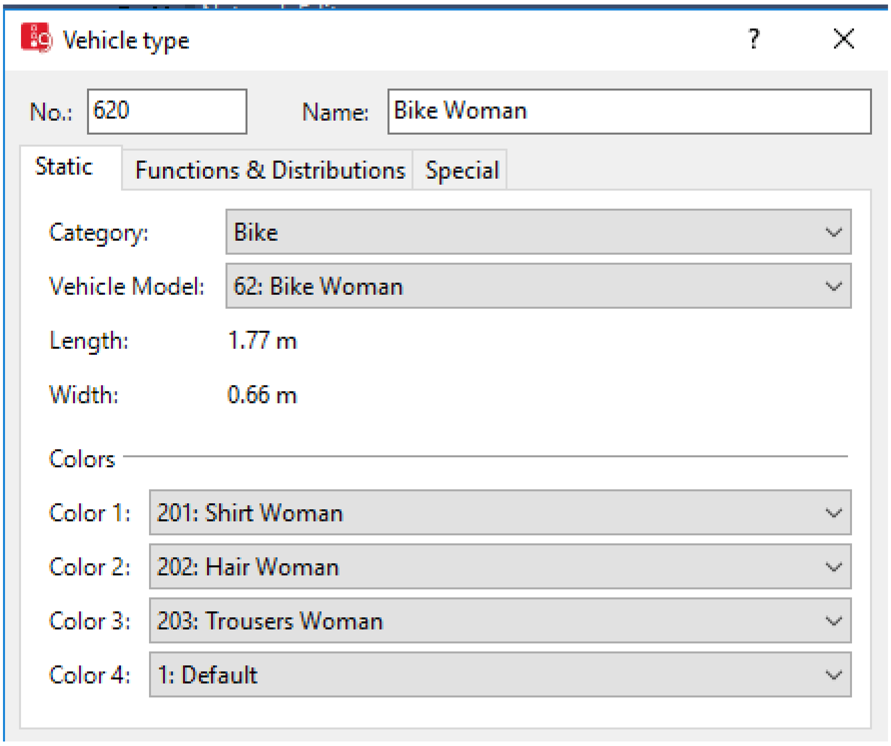


Figure 4.12: Composition of Female Bike Rider

Table 4.6: Summary of traffic compositions

Identification number	Types	Category	Length(m)	Width(m)	Relative flow
100	car	Different types of cars	3.75 – 4.7	1.85 – 2.07	0.5
200	HGV	Heavy Good vehicle	12.4	3.04	0.01
300	Bus	Bus	12.4	3.04	0.3
610	Bike Man	Male motor bike	1.77	0.63	0.09
620	Bike woman	Female motor bike	1.77	0.66	0.02
510	Pedestrian	Man	0.41 – 0.46	0.57 – 0.63	0.4
520	pedestrian	Woman	0.31 – 0.4	0.46 – 0.5	0.4
530	pedestrian	Parent	0.36	0.94	0.2

g. Driver Behaviour based on Wiedemann 99 car following model

The default car Wiedemann 99 car following model was adopted for the modeling of four way road traffic network. The driver's behavior parameter setting is in Figure 4.14. The elements of the behavior parameters were explained in Table 4.7.

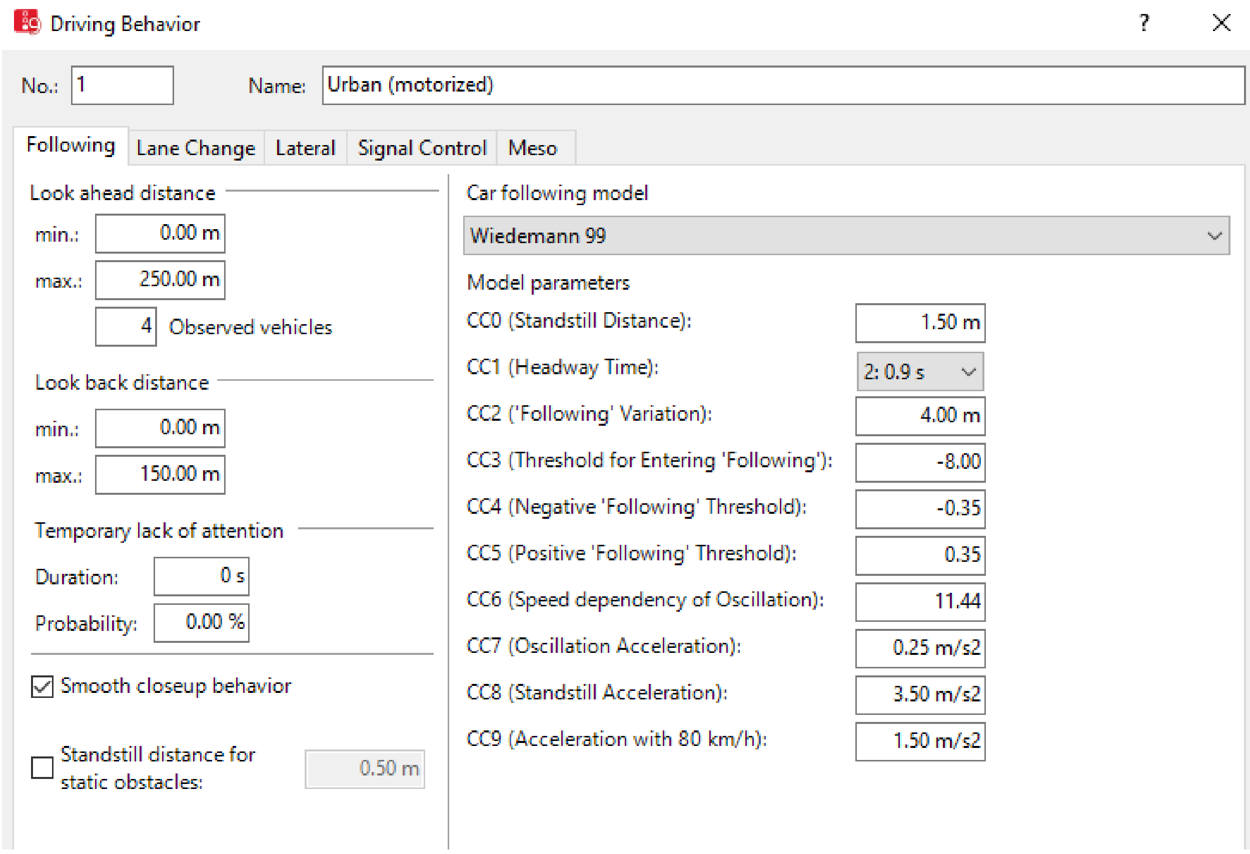


Figure 4.13: Driver's Behaviours parameter settings

Table 4.7: Driver's behavior parameter settings

Parameters	Units	Description
CCO	m	The average desired standstill distance between two vehicles.
CCI	S	Each vehicle has an individual, random safety variable. VISSIM uses this random variable as a fractile for the selected time distribution CC1. This is the distance in seconds which a driver wants to maintain at a certain speed. The higher the value, the more cautious the driver is. The
CC2	m	It restricts the distance difference (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. 10 m, the following behavior results in distances between dx_{safe} and dx_{safe} + 10m. The default value is 4.0m which results in a quite stable following behavior according to VISSIM set up instruction
CC3	s	It controls the start of the deceleration process, i.e. the number of seconds before reaching the safety distance. At this stage the driver recognizes a preceding slower vehicle.
CC4	m/s	Defines negative speed difference during the following process. Low values result in a more sensitive driver reaction to the acceleration or deceleration of the preceding vehicle.
CC5	m/s	Defines positive speed difference during the following process. Enter a positive value for CC5 which corresponds to the negative value of CC4. Low values result in a more

		sensitive driver reaction to the acceleration or deceleration of the preceding vehicle.
CC6	1/(m • s)	Influence of distance on speed oscillation while in following process: Value 0: The speed oscillation is independent of the distance Larger values: Lead to a greater speed oscillation with increasing distance
CC7	m/s^2	Oscillation during acceleration
CC8	m/s^2	Desired acceleration when starting from standstill (limited by maximum acceleration defined within the acceleration curves).
CC9	m/s^2	Desired acceleration at 80 km/h (limited by maximum acceleration defined within the acceleration curves).

4.4.4 Unsignalized Four Way Intersection Road Network with Pedestrians Crossing

General layout explained in subsection 4.4.2 was used for modeling four way unsignalized intersections. Even though there was no signal control, crosswalks were modeled across each vehicle link. Left turn and right turn of vehicles were allowed, vehicles and pedestrians volumes varied as stated in general scenario settings.

Priority rules were used to recognize the right-of-way for vehicles on alternate links according real life traffic situation. Priority rules permit conditional yieldedness to other vehicles when required.

Figure 4.15 is model of a four way intersection road network without signal control. What exist here are freeway operation stop signs. Vehicles stops for pedestrians using priority rules. There is no consideration for pedestrian delay and number of pedestrians on the crosswalk when using priority rules or conflict areas. Delay measurement results were captured and trajectory files obtained from various simulations for performance evaluation. The analyses of the results of this network are reported in Chapter five.

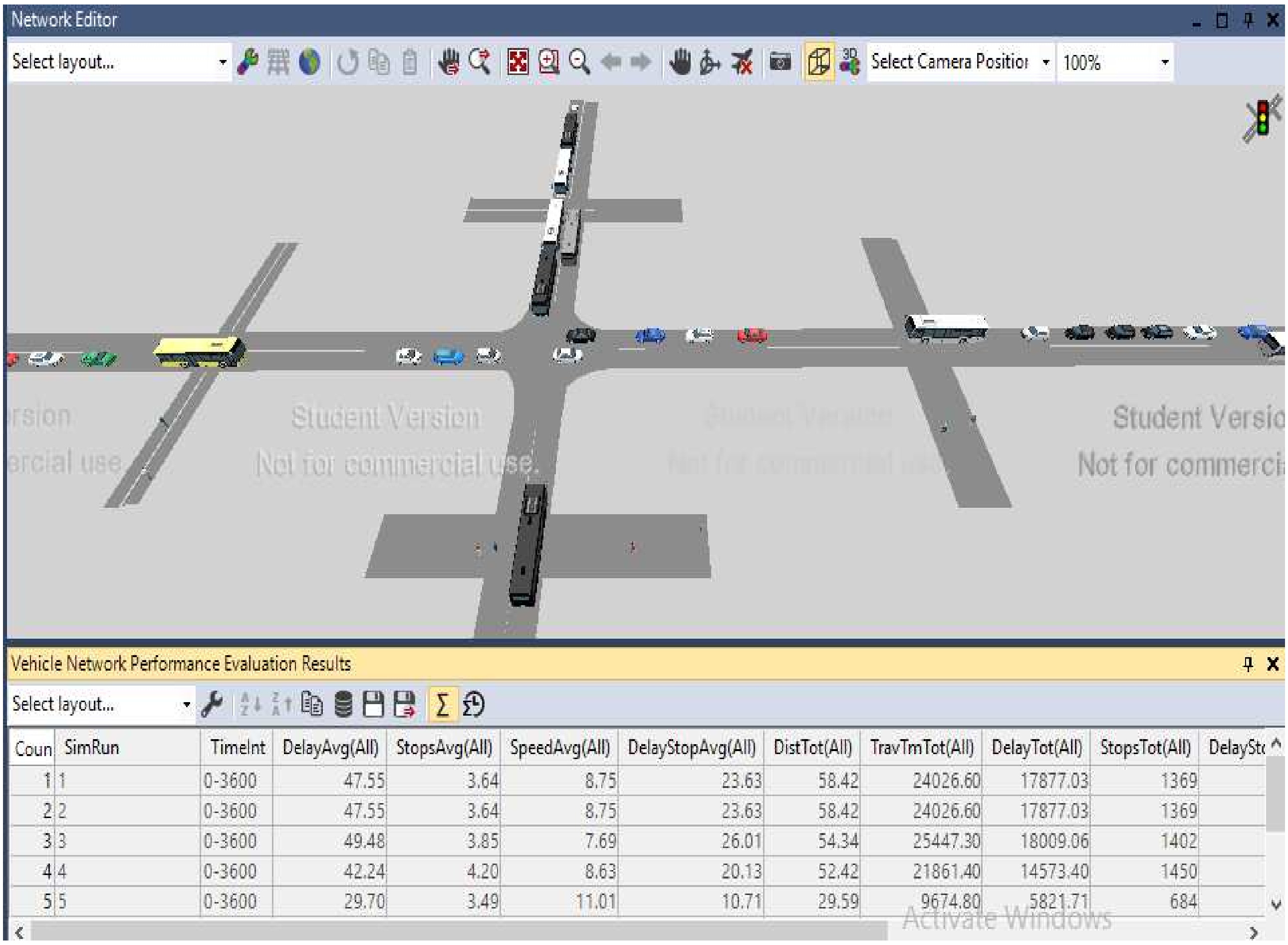


Figure 4.14: Sample Road Network Scenario without signals

4.4.5 Signalized four Way Intersection with Fixed Time Traffic Signal Control Network

Signalized intersections were modeled and evaluated similarly by varying traffic conditions. Left/right turn of vehicles was allowed. Vehicle and pedestrian volumes were varied as in the main simulation settings.

Conflict areas setting was used to complement signal control in determining the right-of-way between conflicting elements. For each area which is conflicting with different flows, VISSIM provides ways of selecting which of the conflicting links has right of way.

The actuated signal controller consists of one signal head for each motorized lanes and two signal heads for each pedestrian crosswalks. The signal heads are controlled by signal programs which consist of signal sequence (red/green/amber) and their time schedules. Microscopic characteristics such as speed profiles, vehicle-type and compositions along with driver behavior parameters can be varied to reflect the practical conditions in real life road network.

A four-lane road intersection along state road, nassarawa area in Kano, Nigeria, was modeled to implement the road network. The intersection comprises of Maiquan Road, Tarauni road, farm center road and state road.

The model of fixed time signal control is placed in Figure 4.16. For fixed time signal control, there were four signal heads for vehicles and four signal head for pedestrians. The signal heads are controlled by fixed signal time allocation programs. From beginning of the simulation each signal head has a fixed time for each of its phases. Several scenarios were implemented varying vehicle volumes from 100 to 1000 on each link and pedestrian traffic volumes from 20 to 120 within each vehicle traffic volume. The delay results for the vehicles and pedestrians were evaluated and used for analysis as represented in chapter five.

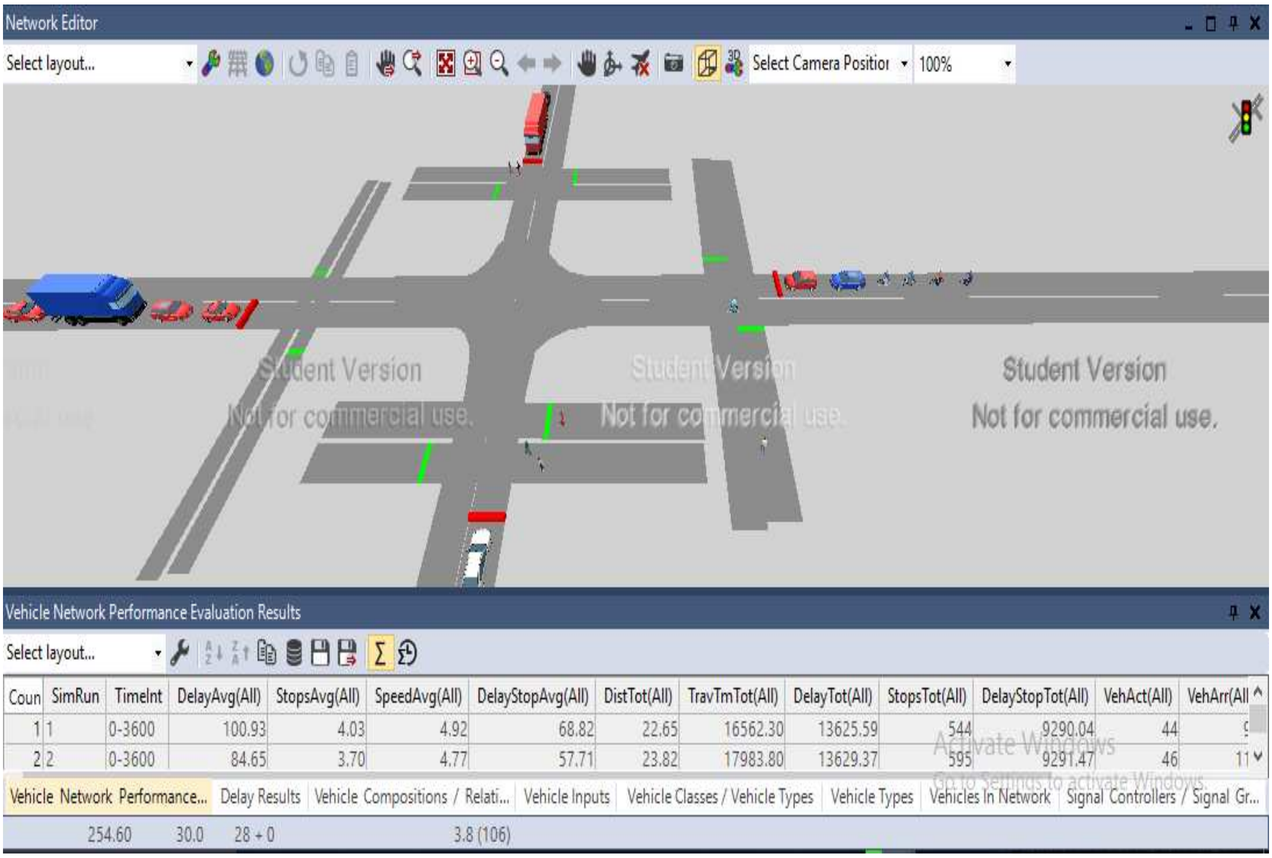
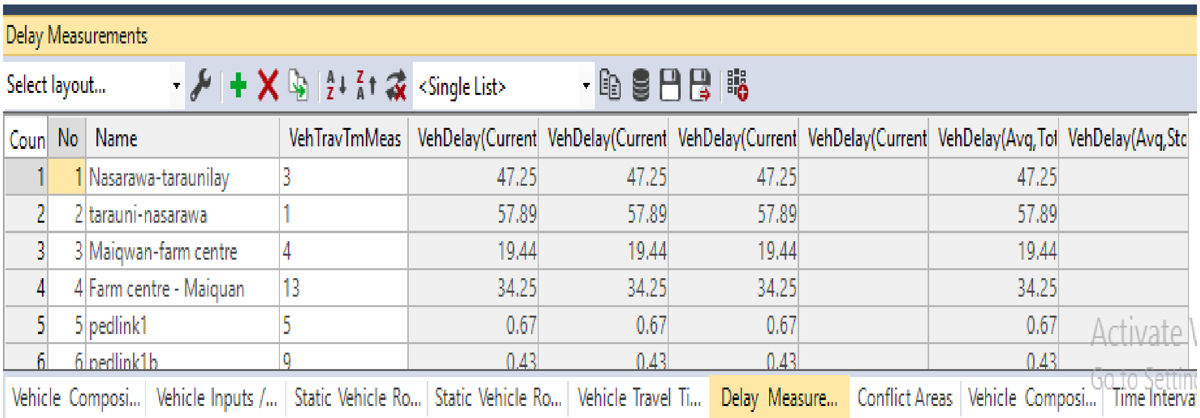


Figure 4.15: Fixed time traffic signal control Network

As simulation runs, delay measurement on each link can be observed according to the delay measurement parameter settings. Link average delay for each simulation runs were computed as well. A sample snapshot of this delay measurement table is represented in Figure 4.17



Coun	No	Name	VehTravTmMeas	VehDelay(Current	VehDelay(Current	VehDelay(Current	VehDelay(Current	VehDelay(Avg,Tot	VehDelay(Avg,Stc
1	1	Nasarawa-taraunilay	3	47.25	47.25	47.25		47.25	
2	2	tarauni-nasarawa	1	57.89	57.89	57.89		57.89	
3	3	Maiqwan-farm centre	4	19.44	19.44	19.44		19.44	
4	4	Farm centre - Maiquan	13	34.25	34.25	34.25		34.25	
5	5	pedlink1	5	0.67	0.67	0.67		0.67	
6	6	pedlink1b	9	0.43	0.43	0.43		0.43	

Figure 4.16: Network delay Measurement window

4.4.6 Fuzzy Intelligent Traffic Control Network.

For the implementation of intelligently influenced network the following were the additional modeling procedures so as to obtain necessary information/data that can be inputted into the fuzzy reasoner for computation of appropriate signal time.

a. placement of detectors on various links for vehicle count

b. configurations to connect detectors to respective signal heads

c. detectors identify each vehicle and pedestrian types for data collection and transfer information to appropriate files. The snapshot of detector window is placed in figure 4. 8

d. The fixed time actuated program was replaced with FITC program from MATLAB using COM interface to control the signal timing allocation.

4.4.6.1 VISSIM COM Interface

The dynamic data exchange algorithm was implemented by interfacing MATLAB and VISSIM simulator through VISSIM COM interface. The exchange of data from the two software was made possible by calling VISSIM through MATLAB codes. The codes for this implementation is in Appendix O

4.4.6.2 FISC Scenarios

The various number of scenarios was used varying pedestrian volumes within each vehicle volume variants. Vehicle volumes varied from 100 to 1000 on each link and pedestrian traffic volumes from 20 to 120 within each vehicle traffic volume. Delay results and traffic trajectory files were evaluated in chapter 5. Figure 4.18 is the snapshot of the model network while figure 4.19 is a sample signal group display.

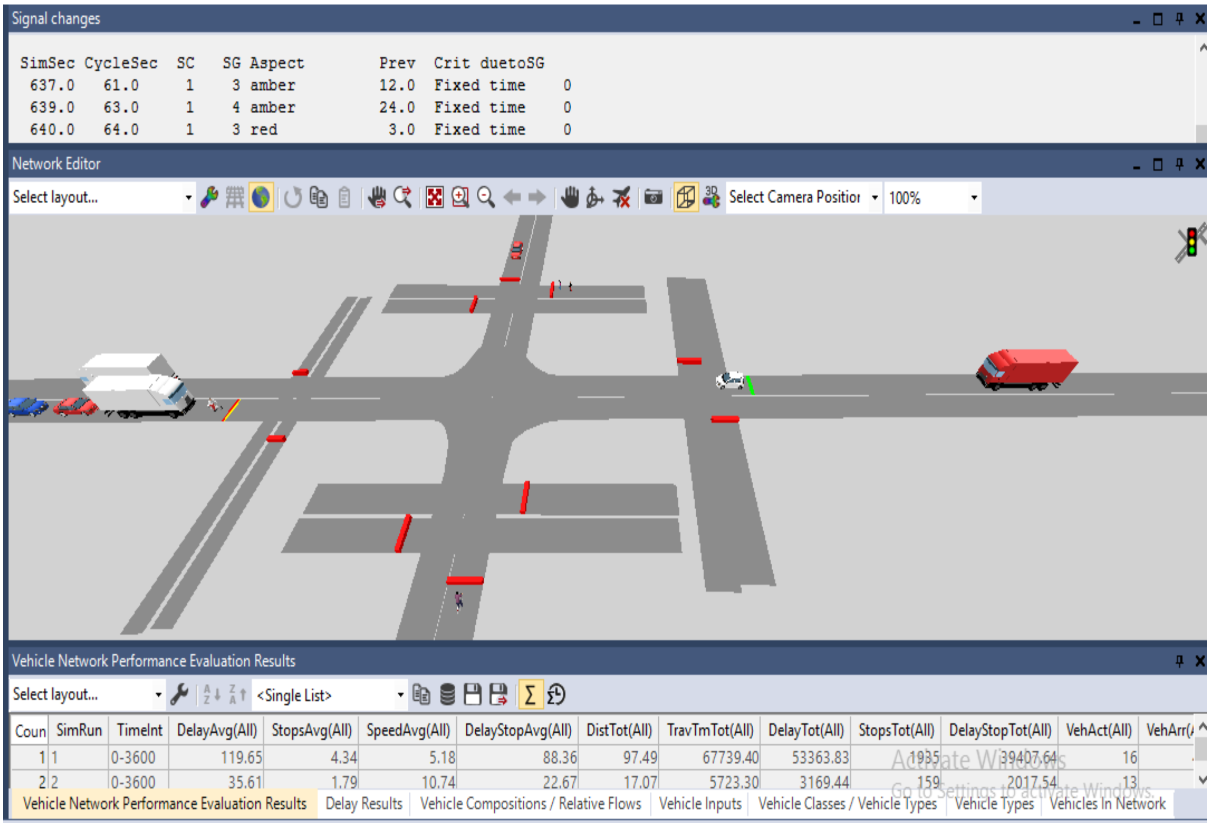


Figure 4.17: Model of FISC Road Network

Figure 4.19 is a representation of signal changes as the simulation runs. Each signal group has indicated control the traffic signal time as informed by the generated signal timing from FITC system. The signal sequence changes dynamically as the traffic demands. The green bars indicate the allocated signal time to the signal heads on the lane.

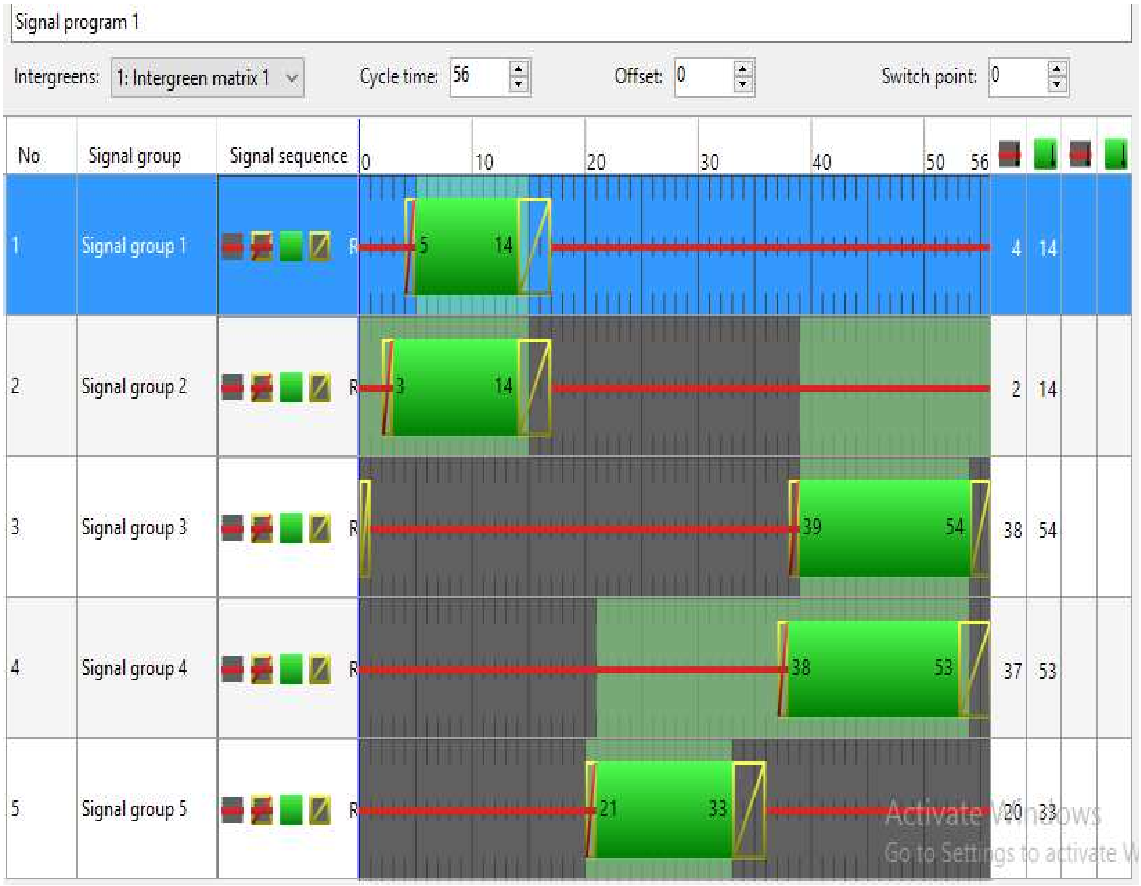


Figure 4.18: Sample Signal Groups display

4.5 Software and Hardware requirements for VISSIM

VISSIM has many ad-on modules such as VisWalk, VISUM and VisVAP for modeling of special systems. Those modules can place additional memory requirements for effective operations. However the general requirements for VISSIM simulator are:

a. Software Requirement: VISSIM and all the Ad-on modules are official product of PTV group with head office in Germany. They are commercial products but free educational versions of VISSIM can be received on request by providing evidence of being a researcher.

i. Operating system: Minimum of Microsoft® Windows® 7, Vista or XP and latest version of windows. For the 64-bit VISSIM edition a 64-bit operating system is essential
ii. Microsoft® .NET Framework 2.0 (language independent installation setup is included in the VISSIM installation package)

b. Hardware

i. Speed: min. 2 GHz (faster computer speed results in faster simulation speed)
ii. Memory (RAM): depending on the application, a minimum of 2 GB is essential. For large networks containing many cars and/or pedestrians more RAM is needed.
iii. Hard disk space: depending on the installation settings up to 2 GB
iv. Functional USB port : at least one
v. Graphics card: for 3D Graphics OpenGL®-support is essential.
vi. Multi-core processors are recommended as VISSIM's multi-thread capability (VISSIM version 5.10 and above) allows parallel computing.

CHAPTER FIVE

SYSTEM EVALUATION AND RESULTS

5.1 Introduction

Unsignalized, signalized fixed time and fuzzy intelligent traffic control models were evaluated using several scenarios varying traffic parameters. The various delay measurement for both vehicles and pedestrians were analyzed. Trajectory files were analyzed using Surrogate Safety Assessment Model (SSAM) to generate the potential conflict as a safety index. The results were discussed, comparism made with standard values and proposed model were calibrated using traffic counts and crash data from Kano, Nigeria.

5.2 Evaluation Parameters

According to the set objectives, average vehicle delay, average Pedestrian delay and potential conflict parameters are the network evaluation parameters.

5.2.1 Average pedestrian delay

This is the average of the sum of the delay of all the pedestrian across the four-way intersection of the network. The individual pedestrian delay is the time it takes for the pedestrian to have the right of way on the road.

5.2.2 Average vehicle delay

Vehicle delay is the difference in the theoretical travel time the vehicle would have used if traveling without any obstruction or interruption by traffic control and the actual travel time of the vehicle in the road network. That is the difference between the expected and the experienced (observed) travel time.

5.2.3 Surrogate Safety Assessment Model Parameters

SSAM is a safety tool box that utilizes the microscopic traffic simulation vehicle trajectories to generate safety performance measures. According to FHWA (2010) the safety parameters are:

a. Minimum Time to Collision (TTC) is the minimum time-to-collision value observed during the conflict. This estimate is based on the current location, speed, and future trajectory of two objects at a given instant. TTC value is defined for each time-step during the conflict event. A conflict event is concluded after the TTC value rises back above the critical threshold value. This value is recorded in seconds.
b. Minimum post-encroachment time (PET) is the minimum post-encroachment time observed during the conflict. PET is the time between when the first object last occupied a position and the time when the second vehicle subsequently arrived at the same position. A value of zero indicates a collision. A conflict event is concluded when the final PET value is recorded at the last location where a TTC value was still below the critical threshold value. This value is recorded in seconds.
c. Initial deceleration rate (DR): *DR* is the initial deceleration rate of the second object, recorded as the instantaneous acceleration rate. If the vehicle brakes (i.e., reacts), this is the first negative acceleration value observed during the conflict. If the vehicle does not decelerate, this is the lowest acceleration value observed during the conflict. This value is expressed in meters per second, depending as specified in the corresponding trajectory file.
d. Maximum speed (MaxS) is the maximum speed of either object throughout the conflict (i.e., while the TTC is less than 1.5 sec). This value is expressed in meters per second,

e. Maximum relative speed difference (DeltaS). *DeltaS* is the difference in objects speeds as observed at tMinTTC (the minimum TTC value). More precisely, this value is mathematically defined as the magnitude of the difference in object's velocities (or trajectories), such that if $v1$ and $v2$ are the velocity vectors of the first and second objects respectively, then DeltaS = $\| v1 - v2 \|$. If both objects are traveling at the same speed, v and in the same direction, DeltaS = 0. If they have a perpendicular crossing path, DeltaS = $(\sqrt{2})v$. If they are approaching each other head on, DeltaS = $2v$.

f. *MaxD* is the maximum deceleration of the second objects, recorded as the minimum instantaneous acceleration rate observed during the conflict. A negative value indicates deceleration (braking or release of gas pedal). A positive value indicates that the vehicle did not decelerate during the conflict. This value is expressed in meters per second.

g. Clash types: *ConflictType*, describes whether the conflict is the result of a rear-end, lane-change, or crossing movement. If link and lane information is not available for both objects, then the event type is classified based solely on the absolute value of the ConflictAngle. The type is classified as a rear-end conflict if ||ConflictAngle|| < 30 degrees, a crossing conflict if ||ConflictAngle|| > 85 degrees, or otherwise a lane-change conflict. The simulation model that produced the vehicle trajectory data can generally provide link and lane information for both vehicles, though the coding of these values may vary significantly from one simulator vendor to the next.

VISSIM has the ability to record the movement of each individual vehicle and pedestrian with all of their associated attributes such as acceleration, direction, and speed and export it to a trajectory file for further analysis. This trajectory file is used as input into the SSAM software for analyzing potential conflicts. The system projects the path of all vehicles and pedestrians and calculates the distance between adjacent objects in the network. Based on the surrogate safety measure, if a vehicle is in close proximity to a pedestrian, the value of TTC will be less than the critical value of 1.5 sec. Then, the SSAM identifies it as a dangerous situation and reports it as a potential conflict.

For every run, the SSAM recorded individual conflicts that were exported in comma separated value (CSV) file. For this research, potential conflict through the analysis of VISSIM trajectory file was used to calculate the crash rate.

5.3 Evaluation Results

5.3.1 Delay Measurement Results

For each vehicular volume, number of simulated pedestrians were varied, average of this variant were calculated for each network scenario group using equation (5.1). The sample vehicle delay results for scenarios is in Appendix N.

$$AVD(j) = \frac{\sum_{i=1}^{n} T_{tm} - T_{ac}}{n} \tag{5.1}$$

where

AVD(j) – average vehicle delay for scenario(j)

$T_{tm\,(i)}$ - Theoretical travel time if no obstruction or interruption on the path of vehicle (i)

$T_{ac(i)}$ - The actual travel time of the vehicle(i) on the road network

n - number of vehicles on the network

Likewise for pedestrians, average pedestrian delay for each scenario were computed using equation (5.2)

$$APD(j) = \frac{\sum_{i}^{n} pd(i)}{n} \tag{5.2}$$

Where

APD(j) - average pedestrian delay for scenario(j)

Pd(i) - individual pedestrian delay

n - total number of simulated pedestrians

a. Fixed Time Traffic Control Delay Result

To evaluate fixed time traffic control network, average vehicle delay was computed from each compound set of scenario's results using Equation (5.3). Likewise the average pedestrian delay for each group of scenarios was computed using Equation (5.4). There were ten groups of scenarios in all and each group of scenarios has five single scenarios in them. For each group of scenarios vehicle volume increases in hundreds while pedestrian volumes increases in tens. Within each group, the pedestrian's volume increases in fives. This is to capture many traffic situations to reflect varying traffics volume in real life.

$$GVD(i) = \frac{\sum_1^n AVD(j)}{n} \qquad (5.3)$$

where

GVD(i) - group(*i*) average vehicle delay

AVD(j) - average delay for scenario(j)

n - number of scenarios in a group(1 to 5)

i - 1 to 10

$$GPD(i) = \frac{\sum_1^n APD(j)}{n} \qquad (5.4)$$

where

GPD(i) - group(*i*) average pedestrian delay

APD(j) - average delay for scenario(j)

n - number of scenarios in a group(1 to 5) i - 1 to 10

Average vehicle delay increases from 22.43 sec to 114.68 sec as traffic volume increases across the groups. The average pedestrian delay ranges from 12.98 sec. to 22.53sec as traffic volume increases across the groups.. This delay result is summarized in Table 5.1.

Table 5.1: Fixed Time Traffic control Vehicle and Pedestrian delay result

Vehicle./Pedestrian Volume	Fixed Time Average Vehicle delay(sec)	Fixed time Average Pedestrian delay(sec)
100/20	22.43	12.98
200/30	45.23	11.83
300/40	66.04	14.13
400/50	76.85	15.63
500/60	82.67	16.78
600/70	83.56	17.93
700/80	103.57	19.08
800/90	109.01	20.23
900/100	110.57	21.38
1000/120	114.68	22.53

b. Fuzzy Intelligent Traffic Control Scenarios Result

The FITC road network model performance evaluation result follows the same format as fixed time traffic control using Equations (5.1) to (5.4). There were ten groups of scenarios and five scenarios within each group. The road network was evaluated with a total of fifty scenarios. For the groups, the average vehicle delay ranges from 19.12sec to 67.48sec, while the pedestrian delay ranges from 9.05sec. to 21.7sec. as traffic volume increases. This results for average vehicle delay and average pedestrian delay for all the groups are in Table 5.2.

Table 5.2: FITC delay result

Veh. /Ped.	Vehicle delay FITC(sec)	Ped. FITC delay (sec)
100/20	19.12	9.05
200/30	25.83	10.39
300/40	40.83	12.32
400/50	48.29	13.66
500/60	47.25	15
600/70	44.75	16.34
700/80	67.59	17.67
800/90	69.02	19.01
900/100	69.94	20.35
1000/120	67.48	21.7

c. Comparative Performance Evaluation for FITC and Fixed Time Traffic Control.

Average vehicle delay for fixed time control network was compared with the delay result obtained from FITC system. The percentage improvement was computed for each compound scenarios using equation (5.3)

$$P_g = \frac{D_{Ft} - D_{FITc}}{D_{FITc}} \; x \; 100\% \qquad (5.3)$$

Where

P_g - Percentage gain/improvement

D_{Ft} - fixed time average delay

D_{FITC} - FITC average delay

Table 5.3 present the comparative result. Across the scenarios, average of 53.19% performance improvement was obtained. This comparism was plotted as displayed in figure 5.1

Table 5.3: Average Vehicular Delay Comparism for fixed time control and FITC

Vehicle/Pedestrian	Fixed time delay(sec)	FITC Delay(sec)	Percentage Gain
100/20	22.43	19.12	17.31
200/30	35.23	25.83	75.11
300/40	66.04	40.83	61.74
400/50	76.85	48.29	59.14
500/60	82.67	47.25	74.96
600/70	83.56	44.75	86.73
700/80	103.57	67.59	53.23
800/90	109.01	69.02	57.94
900/100	110.57	69.94	58.09
1000/120	114.68	67.48	69.95
		Average improvement	53.19%

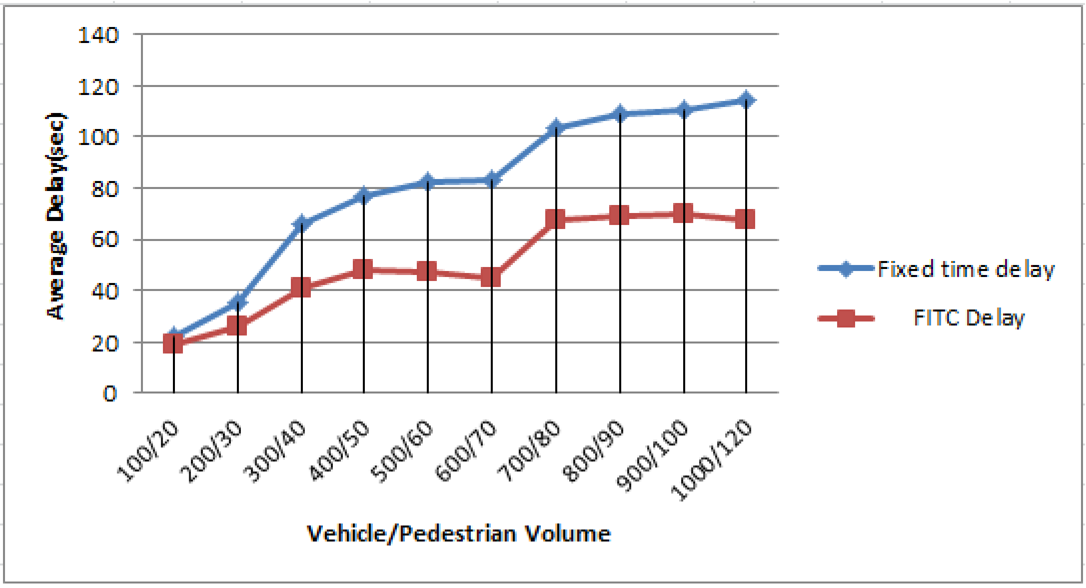


Figure 5.1: Delay plot for fixed time and FITC

5.3.2 Comparing Vehicle Delay Measurement result for FITC Network and HCM Delay

The performance of FITC network was compared with HCM standard delay. The percentage improvement was computed using equation (5.4).

$$P_{gHCM} = \frac{D_{HCM} - D_{FITC}}{D_{FITC}} \quad X \quad 100\% \qquad (5.4)$$

where

P_{gHCM} - percentage gain/loss between HCM minimum standard delay and FITC vehicle delay

D_{HCM} - minimum delay standard value for HCM

D_{FITC} - average delay from FITC

In some scenarios instances FITC performs better while in some scenarios HCM delay values are better. This evaluation was averaged and percentage improvement obtained is 1.18%. This means that average HCM delay is slightly lower than that of FITC. This is display in table 5.4. This majorly occurs during evening hours when both vehicles and pedestrian volumes are likely higher. This is also plotted in Figure 5.2. In other words, for pedestrian needs provisioning, vehicle network might incurred 1.18% delay above the minimum expected.

Table 5.4: HCM recommended delay and FITC delay result

Time	HCM (sec)	FITC (sec)	Percentage gain/loss
07-0800	28.94	19.12	51
08-0900	30.56	25.83	18
09-1000	40.02	40.83	-2
10-1100	49.01	48.29	1
11-1200	49.82	47.25	5
12-1300	49.77	44.75	11
13-1400	50.26	67.59	-26
14-1500	52.23	69.02	-24
15-1500	53.39	69.94	-24
16-1700	49.23	67.48	-27
17-1800	45.24	45.56	-1
		Average Gain/Loss	-1.8%

Chart representation of HCM Vehicle delay and FITC Vehicle delay

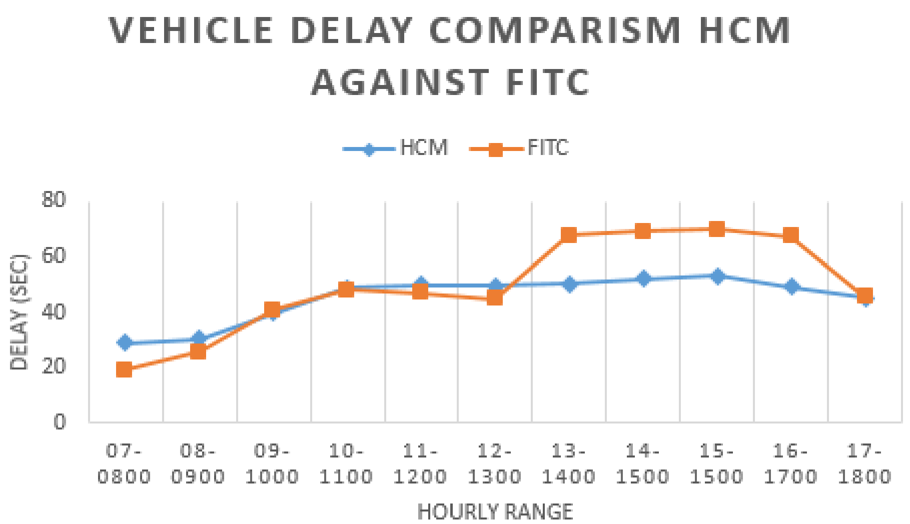


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Figure 5.2: HCM and FITC delay

5.3.3 Comparing Pedestrian Delay Measurement Results

Table 5.5 presents the comparism of pedestrian delay for fixed time and FITC network. The overall improvement average of FITC across the scenarios is 13.13%. This is plotted in figure 5.3.

Table 5.5:Comparing Fixed time and FITC pedestrian delays

Traffic Scenarios	Fixed Time ped delay (sec)	FITC ped delay (sec)	Percentage improvement
100/20	12.98	9.05	43.49
200/30	11.83	10.39	13.86
300/40	14.13	12.32	14.69
400/50	15.63	13.66	14.42
500/60	16.78	15.00	11.87
600/70	17.93	16.34	9.73
700/80	19.08	17.67	7.98
800/90	20.23	19.01	6.42
900/100	21.38	20.35	5.06
1000/120	22.53	21.7	3.82
		Average Improvement	13.13%

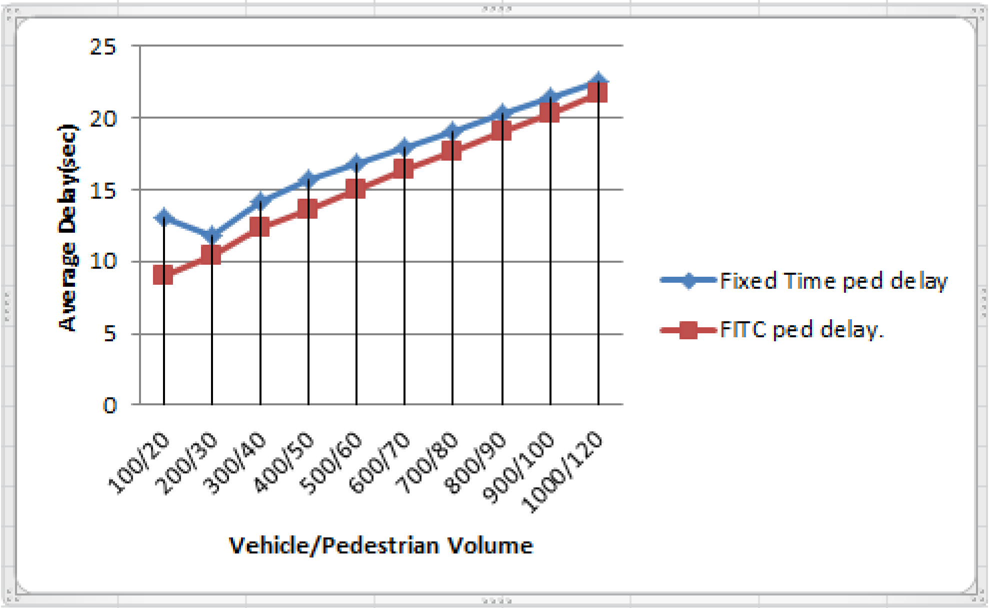

Figure 5.3: Pedestrian delay plot for fixed time and FITC

Pedestrian delay was also compared with standard values. That is the expected average pedestrian delay at intersection. There is a very close correlation between the values. Table 5.6 and Figure 5.4 displayed these.

Table 5.6: Pedestrian Delay and Standard delay values

Traffic	Standard delay (sec)	Pedestrain FITC delay (sec)
100/20	3	9.05
200/30	6	10.39
300/40	9	12.32
400/50	11	13.66
500/60	14	15
600/70	16	16.34
700/80	17	17.67
800/90	20	19.01
900/100	22	20.35
1000/120	24	21.7

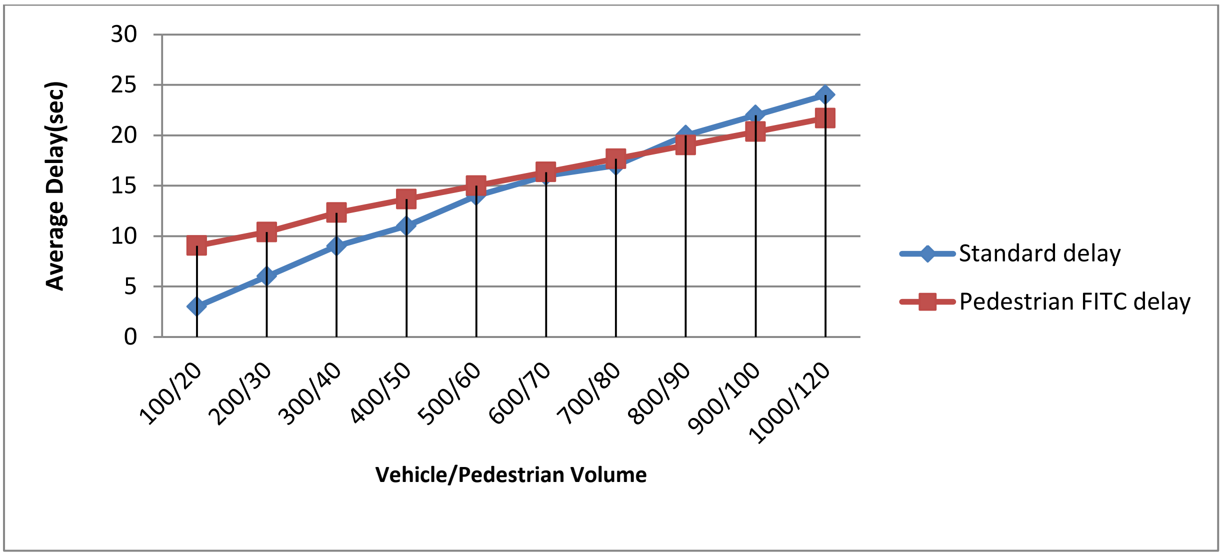

Figure 5.4: Pedestrian delay of FITC and standard pedestrian HCM delay

According to ODOT (2011) report, summarized maximum pedestrian delay from five countries ranges from 30 to 60 seconds as displayed in table 5.7. Using this table as well to compare the pedestrian delay obtained from FITC, the values still fell within the range.

Table 5.7: Selected thresholds for maximum pedestrian delay at signalized intersections from five major countries (ODOT, 2011)

Location	Max. Recommended Ped. Delay (s)
Germany	60
Florida	40

Australia	30
Great Britain	30
United States	30

5.4 SSAM Performance Evaluation Result

VISSIM trajectory files for fixed time traffic and FITC were analyzed, the crash analysis report summary are represented in Tables 5.7 and 5.8 respectively. Five(5) potential crash cases were reported for fixed time and one(1) potential crash case was reported for FITC based on TTC <=1.5sec.

Unsignalized Model Crash Report

SSAM_Measure	Min	Max	Mean	Variance	
TTC(sec)	0	1.5	1.14054	0.186366	
PET(sec)	0	4.8	2.42703	1.76758	
MaxS(m/s)	1.32762	14.6336	4.57359	11.2026	
DeltaS(m/s)	4.61E-05	14.1604	2.98016	12.9429	
DR (m/s)	-8.86473	0	-2.30833	5.57973	
MaxD (m/s)	-10	0	-4.37121	6.74345	
MaxDeltaV (m/s)	2.98E-05	14.074	2.24006	12.166	
Summary					
Total	unclassified	crossing	rear end	lane change	
37	0	4	33	0	
37	0	4	33	0	

Table 5.8: Fixed Time Model Crash Report

SSAM Measurement	Minimum	Maximum	Mean	Variance
TTC(sec)	0.8	1.50	1.28	0.09
PET(sec)	1.20	4.10	2.12	1.40
MaxS(m/s)	1.45	15.48	5.24	33.57
DeltaS(m/s)	0.79	15.65	4.45	39.74
DR (m/s)	-10.00	0.00	-4.52	21.54
MaxD (m/s)	-10.00	0.00	-5.16	20.99
MaxDeltaV (m/s)	0.41	15.39	3.86	41.80
Total potential Crash	Unclassified	Crossing	Rearend	lanechange
5	0	1	4	0

Table 5.9: FITC potential crash report

SSAM Measurement	Minimum	Maximum	Mean	Variance
TTC	0.9	0.9	0.9	0
PET	1.19998	1.19998	1.19998	0
MaxS	1.32762	1.32762	1.32762	0
DeltaS	0.213702	0.213702	0.213702	0
DR	-10	-10	-10	0
MaxD	-10	-10	-10	0
MaxDeltaV	0.138099	0.138099	0.138099	0.138099
Total potential Crash	Unclassified	Crossing	Rearend	lanechange
1	0	0	1	0

Table 5.10: Potential Crash summary

Vehicle Volume	**Pedestrian Vol.**	**TTC Value(sec)**	**Total Clash**	**Traffic control**
4000	968	<= 1.5	1	FITC
4000	968	<= 1.5	5	Fixed time
4000	968	<=1.5	37	Unsignalized

5.4.1. Crash Rate Analysis

Crash rate (per million entering vehicles) takes into account the total number of crashes compared to the average traffic volume.

Crash rate for the fixed time, FITC system and real life crash cases from Kano, Nigeria (Appendix F) was computed and compared to assess the safety improvement of the system. According to ODOT (2011), crash can be computed according to Equation (5.4)

$$\text{Crash rate} = \frac{\text{N}}{(\sum ADT)*3\ years*365\ days*10-6} \qquad (5.4)$$

where,

ADT = is the average daily traffic entering the intersection

N = the total number of crashes at the particular location

Kano crash analysis result based on Equation 5.4 is represented in Table 5.11

Table 5.11: Kano five year crash rate (FRSC, kano)

Year	Avg. daily vehicle count	Crash cases	crash rate
2014	8474	28	3.02
2013	7868	36	4.18
2012	7950	21	2.41
2011	7412	17	2.09
2010	8999	24	2.44
		Five years crash rate average	2.83

From Table 5.11, the crash rate of FITC system has the smallest crash rate. This indicates that it is a safer system.

Table 5.12: Real life crash rate and Potential Crash rate from simulated traffic

	Traffic count	Crash rate
Fixed time	9936	1.84
Fuzzy Int.	9936	0.37
Real life crash rate	8948	2.83

5.5 Calibration and Validation

According to ODOT (2011), Geoffrey E. Havers as a transport planner in 1970, in London invented an empirical calibration formula known as GEH. This according to the report has proved useful for variety of traffic analysis purposes. The use of GEH best suit traffic volumes that varied over a wide range of values in real life.

$$GEH = \sqrt{\frac{2(m-c)^2}{m+c}} \quad (5.5)$$

Where

c - the hourly real life count

m - the simulated hourly count

Sample Computation using Equation (5.5)

$$GEH = \sqrt{\frac{2\,(541-624)^{\,2}}{541+624}}$$

$$GEH = \sqrt{\frac{13778}{1165}}$$

$$GEH = \sqrt{11.8260}$$

GEH = 3.43

Table 5.13: GEH Acceptable Range

Value of statistic	Criteria
GEH < 5.0	Acceptable fit
5.0 < = GEH <= 10.0	Caution: possible model error or bad data
GEH> 10.0	Unacceptable

5.5.1 Vehicle Volume Calibration

Using Table 5.13 to assess Table 5.14, all the scenarios calibrated have acceptable GEH values. The vehicle simulated output volume and real life count were plotted in Figure 5.5

Table 5.14: Real life vehicle count and simulated count validation

TIME	Veh. count	Veh. simulated(M)	Computed GEH
06-0700	624	541	3.43
07-0800	691	599	3.60
08-0900	508	441	3.09
09-1000	711	617	3.66
10-1100	789	684	3.85
11-1200	804	697	3.89
12-1300	843	731	3.98
13-1400	826	717	3.94
14-1500	728	632	3.70
15-1500	833	723	3.96
16-1700	766	665	3.80
17-1800	876	760	4.06

As reflected in Figure 5.5, there was a close gap between the input according to real life traffic counts and the simulated vehicle counts in FITC road network model.

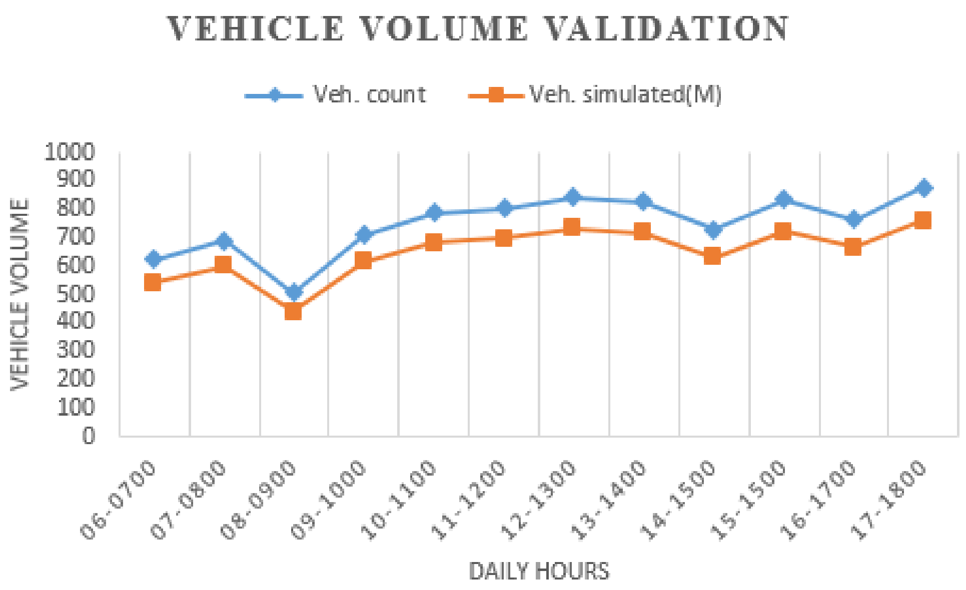

Figure 5.5: Plot of real life Veh. and simulated Veh. Count

5.5.2. Pedestrian Volume Validation

As the vehicle volumes were validated, pedestrian volumes were also validated with pedestrian volume input ranges from 60 to 480. The correlation between the input and output is plotted in Figure 5.6. The resulting GEH values ranges from 1.63 to 4.77 as display in Tables 5.15 and Table 5.16. This confirmed acceptable validation of the system.

Table 5.15: displays the simulated pedestrian traffic input and output with the GEH acceptable values.

Traffic Scenarios	Ped. Input	Ped Output	GEH
1	60	48	1.63
2	120	91	2.82
3	180	149	2.42
4	240	190	3.41
5	300	238	3.78
6	360	285	4.18
7	420	333	4.48
8	480	381	4.77

Table 5.15: Pedestrian validation summary report

traffic	FITC GEH range	Acceptable Value	Evaluation
Pedestrian	1.63-4.77	<=5.0	Acceptable fit

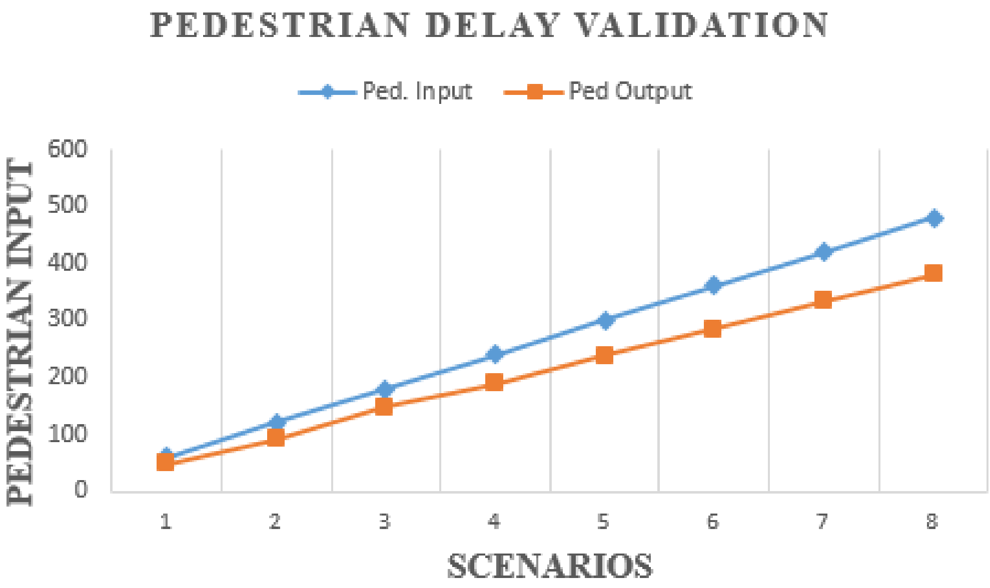

Figure 5.6: Input and Output simulated pedestrian volume

5.6 Research Evaluation Summary and Previous Research

As reflected in section 2.6.2 of literature review, Alam and Pandey (2014) designed a fuzzy intelligent system to reduce congestion on the road network. The work compared the fuzzy intelligent system with fixed time signal control system and accomplished 35.47% improvement while this proposed FITC achieved 53.19% improvement over fixed time traffic control system. Agarwal (2011) worked on pedestrian safety at traffic junction without considering traffic delays and using SSAM a potential crash rate of 1.19 was achieved. The proposed FITC safety inclined system achieved a potential crash rate of 0.37 as represented in Table 5.16

Table 5.16: comparing FITC with previous research

Traffic control Design	Potential conflict rate	Percentage Delay improvement
FITC	0.37	53.19%
Alam and Pandy (2014)	-	35.47%
Agarwal(2011)	1.19	-
Hassan (2013)	-	17.8%(ped), -20.8%(Veh)

CHAPTER SIX

SUMMARY, CONCLUSION AND FUTURE WORKS

6.1 Introduction

This chapter contains the summary of the research, the conclusion derived from the research, and recommendations for future works.

6.2 Research Summary

Through this research, investigation into literature revealed a research gap in provision of a safe driven pedestrian right of way without vehicle delay on major roads. It was also discovered that increased pedestrian waiting time is a major factor to high crash rate on urban areas. As the volume of car increases it becomes more difficult for pedestrians to cross major roads safely, hence, pedestrian waiting time becomes unbearable. This research designed architectural and conceptual model for vehicle-pedestrian interaction for four way intersection. Fuzzy logic intelligent system was developed for a sensitive interaction between the vehicles and pedestrians. The system is sensitive to both pedestrian and vehicular traffic in allocating signal time, hence, harmonizing the conflicting interest of vehicle drivers and pedestrians.

The proposed system was implemented using a four way intersection in Kano. The traffic model was built in VISSIM traffic simulator. The model was evaluated using several traffic scenarios. Evaluation results indicate that the proposed system will help to reduce pedestrian delay and improve safety of life on the road. Calibration and validation of the models give acceptable result.

6.3 Conclusion

This research has demonstrated that it is possible to intelligently take into consideration the interest of various road users in signal time allocation at signalized intersections. It is also clear from this research that adequate reduction of pedestrian delay enhances reduction of crash rate and thereby improves safety. From the evaluation of the system the following conclusions can be drawn.

a. FITC achieved average improvement of 53.19% over Fixed time traffic control
b. FITC Pedestrian delay improves by 13.13% over Fixed time. FITC also achieved maximum delay of 20.35sec per pedestrian and it falls within acceptable fit of less than 50sec (HCM, 2000).
c. Potential crash rate of 0.37 for a traffic flow of approx. 9000 as against real life crash rate of 2.83.
d. Calibration of models also gave acceptable GEH value of less than 5.0.

6.4 Recommendation

a. Land use should be a major consideration in planning road network. Roads that will be close to market places, schools and cinema houses that attract higher number of pedestrians should provide intelligent crossing system for pedestrian safety.

b. Safety awareness should be incorporated to school programmes and staff development programmes.

c. Road safety officials should be ICT compliance to be able to enforce the use of Intelligent Transportation Systems

6.5 Future Research Work

a. The intelligent system can also be implemented with other Artificial Intelligent methods. This research used fuzzy logic for reasoning, as variable increases the number of rules increases.

b. Incorporation of priority pedestrian or VIP service at intersections can also be considered. It is also necessary to have priority crossing in case of emergency.

c. Other road infrastructure such as Roundabouts can be designed with pedestrian crossing intelligently incorporated. Road complimentary facilities are location dependent. That is, there are specific locations where four ways intersection is the best, there are other locations where other facilities like roundabout are most suitable. Each of these areas needs to make intelligent provision for pedestrian's safety.

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APPENDICES

Appendix A: Fuzzy Inference Codes in MATLAB

1. [System]
2. Name='veh-pedcontrol'
3. Type='mamdani'
4. Version=2.0
5. NumInputs=4
6. NumOutputs=1
7. NumRules=162
8. AndMethod='min'
9. OrMethod='max'
10. ImpMethod='min'
11. pAggMethod='max'
12. DefuzzMethod='centroid'

13. [Input1]
14. Name='peddelay'
15. Range=[0 600]
16. NumMFs=3
17. MF1='short':'trapmf',[0 15 50 70]
18. MF2='medium':'trapmf',[39.5592063492063 231.549206349206 279.549206349206 471.549206349206]
19. MF3='long':'trapmf',[215.7 407.7 455.7 647.7]

20. [Input2]
21. Name='totalped'
22. Range=[0 60]
23. NumMFs=3
24. MF1='few':'trapmf',[-21.6 -2.4 2.4 21.6]
25. MF2='many':'trapmf',[8.4 27.6 32.4 51.6]
26. MF3='very_many':'trapmf',[38.4 57.6 62.4 81.6]

27. [Input3]
28. Name='vqueue'
29. Range=[0 50]
30. NumMFs=3
31. MF1='short':'trapmf',[-18 -2 2 18]
32. MF2='medium':'trapmf',[7 23 27 43]
33. MF3='long':'trapmf',[32 48 52 68]

34. [Input4]
35. Name='weather'

36. Range=[0 1]
37. NumMFs=2
38. MF1='raining':'trimf',[-0.4 0 0.4]
39. MF2='norain':'trimf',[0.211111111111111 0.611111111111111 1.01111111111111]

40. [Output1]
41. Name='signtime'
42. Range=[0 1]
43. NumMFs=3
44. MF1='short':'trapmf',[-0.36 -0.04 0.04 0.36]
45. MF2='medium':'trapmf',[0.14 0.46 0.54 0.86]
46. MF3='long':'trapmf',[0.64 0.96 1.04 1.36]

47. [Rules]
48. 1 1 1 1, 1 (1) : 1
49. 1 1 1 1, 2 (0.35) : 1
50. 1 1 1 1, 3 (0.26) : 1
51. 1 1 1 2, 1 (0.83) : 1
52. 1 1 1 2, 2 (0.82) : 1
53. 1 1 1 2, 3 (0.98) : 1
54. 1 1 2 1, 1 (0.79) : 1
55. 1 1 2 1, 2 (0.55) : 1
56. 1 1 2 1, 3 (0.9) : 1
57. 1 1 2 2, 1 (0.57) : 1
58. 1 1 2 2, 2 (0.27) : 1
59. 1 1 2 2, 3 (0.27) : 1
60. 1 1 3 1, 1 (0.21) : 1
61. 1 1 3 1, 2 (0.41) : 1
62. 1 1 3 1, 3 (0.72) : 1
63. 1 1 3 2, 1 (0.47) : 1
64. 1 1 3 2, 2 (0.56) : 1
65. 1 1 3 2, 3 (0.84) : 1
66. 1 2 1 1, 1 (0.16) : 1
67. 1 2 1 1, 2 (0.83) : 1
68. 1 2 1 1, 3 (0.16) : 1
69. 1 2 1 2, 1 (0.79) : 1
70. 1 2 1 2, 2 (0.5) : 1
71. 1 2 1 2, 3 (0.73) : 1
72. 1 2 2 1, 1 (0.05) : 1
73. 1 2 2 1, 2 (0.2) : 1
74. 1 2 2 1, 3 (0.3) : 1
75. 1 2 2 2, 1 (0.47) : 1
76. 1 2 2 2, 2 (0.18) : 1
77. 1 2 2 2, 3 (0.18) : 1
78. 1 2 3 1, 1 (0.15) : 1
79. 1 2 3 1, 2 (0.33) : 1
80. 1 2 3 1, 3 (0.93) : 1

81. 1 2 3 2, 1 (0.09) : 1
82. 1 2 3 2, 2 (0.99) : 1
83. 1 2 3 2, 3 (0.75) : 1
84. 1 3 1 1, 1 (0.67) : 1
85. 1 3 1 1, 2 (0.2) : 1
86. 1 3 1 1, 3 (0.63) : 1
87. 1 3 1 2, 1 (0.09) : 1
88. 1 3 1 2, 2 (0.64) : 1
89. 1 3 1 2, 3 (0.36) : 1
90. 1 3 2 1, 1 (0.94) : 1
91. 1 3 2 1, 2 (0.86) : 1
92. 1 3 2 1, 3 (0.13) : 1
93. 1 3 2 2, 1 (0.6) : 1
94. 1 3 2 2, 2 (0.62) : 1
95. 1 3 2 2, 3 (0.96) : 1
96. 1 3 3 1, 1 (0.09) : 1
97. 1 3 3 1, 2 (0.75) : 1
98. 1 3 3 1, 3 (0.65) : 1
99. 1 3 3 2, 1 (0.84) : 1
100. 1 3 3 2, 2 (0.61) : 1
101. 1 3 3 2, 3 (0.72) : 1
102. 2 1 1 1, 1 (0.03) : 1
103. 2 1 1 1, 2 (0.5) : 1
104. 2 1 1 1, 3 (0.25) : 1
105. 2 1 1 2, 1 (0.16) : 1
106. 2 1 1 2, 2 (0.68) : 1
107. 2 1 1 2, 3 (0.88) : 1
108. 2 1 2 1, 1 (0.97) : 1
109. 2 1 2 1, 2 (0.13) : 1
110. 2 1 2 1, 3 (0.39) : 1
111. 2 1 2 2, 1 (0.65) : 1
112. 2 1 2 2, 2 (0.35) : 1
113. 2 1 2 2, 3 (0.58) : 1
114. 2 1 3 1, 1 (0.22) : 1
115. 2 1 3 1, 2 (0.8) : 1
116. 2 1 3 1, 3 (0.62) : 1
117. 2 1 3 2, 1 (0.77) : 1
118. 2 1 3 2, 2 (0.96) : 1
119. 2 1 3 2, 3 (0.48) : 1
120. 2 2 1 1, 1 (0.12) : 1
121. 2 2 1 1, 2 (0.95) : 1
122. 2 2 1 1, 3 (0.73) : 1
123. 2 2 1 2, 1 (0.55) : 1
124. 2 2 1 2, 2 (0.16) : 1
125. 2 2 1 2, 3 (0.81) : 1
126. 2 2 2 1, 1 (0.87) : 1
127. 2 2 2 1, 2 (0.9) : 1
128. 2 2 2 1, 3 (0.89) : 1
129. 2 2 2 2, 1 (0.09) : 1
130. 2 2 2 2, 2 (0.16) : 1

131. 2 2 2 2, 3 (0.81) : 1
132. 2 2 3 1, 1 (0.28) : 1
133. 2 2 3 1, 2 (0.77) : 1
134. 2 2 3 1, 3 (0.52) : 1
135. 2 2 3 2, 1 (0.66) : 1
136. 2 2 3 2, 2 (0.59) : 1
137. 2 2 3 2, 3 (0.71) : 1
138. 2 3 1 1, 1 (0.96) : 1
139. 2 3 1 1, 2 (0.84) : 1
140. 2 3 1 1, 3 (0.56) : 1
141. 2 3 1 2, 1 (0.27) : 1
142. 2 3 1 2, 2 (0.21) : 1
143. 2 3 1 2, 3 (0.38) : 1
144. 2 3 2 1, 1 (0.67) : 1
145. 2 3 2 1, 2 (0.59) : 1
146. 2 3 2 1, 3 (0.58) : 1
147. 2 3 2 2, 1 (0.82) : 1
148. 2 3 2 2, 2 (0.65) : 1
149. 2 3 2 2, 3 (0.23) : 1
150. 2 3 3 1, 1 (0.49) : 1
151. 2 3 3 1, 2 (0.7) : 1
152. 2 3 3 1, 3 (0.66) : 1
153. 2 3 3 2, 1 (0.8) : 1
154. 2 3 3 2, 2 (0.52) : 1
155. 2 3 3 2, 3 (0.84) : 1
156. 3 1 1 1, 1 (0.2) : 1
157. 3 1 1 1, 2 (0.22) : 1
158. 3 1 1 1, 3 (0.98) : 1
159. 3 1 1 2, 1 (0.51) : 1
160. 3 1 1 2, 2 (0.38) : 1
161. 3 1 1 2, 3 (0.24) : 1
162. 3 1 2 1, 1 (0.11) : 1
163. 3 1 2 1, 2 (0.05) : 1
164. 3 1 2 1, 3 (0.36) : 1
165. 3 1 2 2, 1 (1) : 1
166. 3 1 2 2, 2 (0.96) : 1
167. 3 1 2 2, 3 (0.4) : 1
168. 3 1 3 1, 1 (0.77) : 1
169. 3 1 3 1, 2 (0.1) : 1
170. 3 1 3 1, 3 (0.83) : 1
171. 3 1 3 2, 1 (0.79) : 1
172. 3 1 3 2, 2 (0.88) : 1
173. 3 1 3 2, 3 (0.08) : 1
174. 3 2 1 1, 1 (0.54) : 1
175. 3 2 1 1, 2 (0.16) : 1
176. 3 2 1 1, 3 (0.27) : 1
177. 3 2 1 2, 1 (0.6) : 1
178. 3 2 1 2, 2 (0.28) : 1
179. 3 2 1 2, 3 (0.63) : 1
180. 3 2 2 1, 1 (0.48) : 1

181. 3 2 2 1, 2 (0.4) : 1
182. 3 2 2 1, 3 (0.39) : 1
183. 3 2 2 2, 1 (0.98) : 1
184. 3 2 2 2, 2 (0.73) : 1
185. 3 2 2 2, 3 (0.78) : 1
186. 3 2 3 1, 1 (0.59) : 1
187. 3 2 3 1, 2 (0.25) : 1
188. 3 2 3 1, 3 (0.62) : 1
189. 3 2 3 2, 1 (0.24) : 1
190. 3 2 3 2, 2 (0.32) : 1
191. 3 2 3 2, 3 (0.26) : 1
192. 3 3 1 1, 1 (0.22) : 1
193. 3 3 1 1, 2 (0.6) : 1
194. 3 3 1 1, 3 (0.23) : 1
195. 3 3 1 2, 1 (0.8) : 1
196. 3 3 1 2, 2 (0.7) : 1
197. 3 3 1 2, 3 (0.09) : 1
198. 3 3 2 1, 1 (0.58) : 1
199. 3 3 2 1, 2 (0.8) : 1
200. 3 3 2 1, 3 (0.47) : 1
201. 3 3 2 2, 1 (0.99) : 1
202. 3 3 2 2, 2 (0.58) : 1
203. 3 3 2 2, 3 (0.52) : 1
204. 3 3 3 1, 1 (0.72) : 1
205. 3 3 3 1, 2 (0.04) : 1
206. 3 3 3 1, 3 (0.23) : 1
207. 3 3 3 2, 1 (0.7) : 1
208. 3 3 3 2, 2 (0.88) : 1
209. 3 3 3 2, 3 (0.79) : 1

Appendix B : Traffic Count Collation and Average Pedestrian Delay (FRSC, 2014)

Kano – Zaria road Time of the day	Traffic vol./hour	Pedestrian delay(sec)
06-07 am	770	180
07-08 am	855	210
08-09am	1928	300
09 – 10 am	1247	170
10 – 11 am	1321	180
11 – 12 am	1316	180
12 – 13 pm	1404	197
13 – 14 pm	1362	195
14 – 15 pm	1198	120
15 – 16 pm	1305	177
16 – 17 pm	1159	115
17 - 18 pm	1123	113
Total	14988	

Appendix C: Pedestrians crossing uninterrupted Traffic Streams (sec/ped.)

Situation	Traffic Flow	Pedestrian Crossing Time (sec)								
	(veh/h)	4	6	8	10	12	14	16	18	20
Single Lane Uninterrupted Traffic Flow	200	1	1	2	4	5	8	11	14	18
	400	1	3	6	10	16	24	35	50	70
	600	2	6	12	23	40	67	108	171	267
	800	4	11	26	55	111	215	409		
	1000	6	22	64	169	429				
	1200	12	58	241						
	1400	32	324							
	1600	415								
Two Lane Uninterrupted Traffic Flow	200	0	1	2	3	5	7	10	13	17
	400	1	3	5	9	14	22	32	45	62
	600	2	5	10	19	32	52	82	125	190
	800	3	8	18	36	68	122	213	366	
	1000	4	13	32	71	149	304			
	1200	6	21	58	148	358				
	1400	9	35	112	337					
	1600	14	62	239						
	1800	21	119							
	2000	36	263							
	2200	67								
	2400	150								
	2600	452								
More Than Two Lanes Uninterrupted Traffic Flow	200	1	2	3	4	6	9	12	15	19
	400	2	4	7	11	17	25	36	50	68
	600	3	7	13	23	38	61	95	146	221
	800	4	11	23	45	84	150	263	455	
	1000	7	18	42	93	196	402			
	1200	10	30	81	207					
	1400	14	52	169						
	1600	23	99	399						
	1800	38	213							
	2000	70								
	2200	150								
	2400	413								

Appendix D: Average delay of pedestrians crossing interrupted Traffic Streams (sec/ped.)

Situation	Traffic Flow	Pedestrian Crossing Time (sec)								
	(veh/h)	4	6	8	10	12	14	16	18	20
Single Lane Interrupted Traffic Flow	200	1	1	2	3	5	6	9	11	14
	400	1	3	5	7	10	15	20	27	35
	600	3	5	8	12	18	26	37	50	67
	800	4	8	13	20	30	43	61	85	117
	1000	7	12	20	32	48	71	103	148	210
	1200	12	20	34	54	86	132	200	301	448
	1400	20	37	67	117	202	343			
	1600	42	108	269						
Two Lane Interrupted Traffic Flow	200	0	1	2	3	4	6	8	10	13
	400	1	2	3	5	8	11	15	21	27
	600	1	3	5	8	11	16	22	30	39
	800	2	4	6	10	14	20	28	38	50
	1000	3	5	8	12	17	24	32	43	57
	1200	4	6	9	14	20	27	36	48	62
	1400	5	8	12	16	22	30	40	52	67
	1600	7	10	14	19	26	34	44	57	72
	1800	10	13	18	23	31	39	50	63	78
	2000	13	17	23	29	37	46	58	71	87
	2200	18	23	29	37	45	56	68	83	101
	2400	25	31	39	47	57	70	84	101	120
	2600	35	43	52	63	75	90	107	127	151
	2800	50	60	72	85	102	121	144	170	201
	3000	71	85	102	122	147	175	209	248	295
	3200	103	128	157	194	238	291	357	436	
	3400	171	235	323	442					
More Than Two Lanes Interrupted Traffic Flow	200	1	2	3	4	5	7	9	11	14
	400	2	3	5	7	10	13	17	23	29
	600	3	4	6	9	13	19	25	33	43
	800	4	5	8	12	17	23	31	41	54
	1000	5	7	10	14	20	27	36	48	62
	1200	6	8	12	17	23	31	40	53	68
	1400	8	10	14	19	26	34	45	57	73
	1600	10	13	17	23	30	39	49	62	78
	1800	13	16	21	27	35	44	55	69	85
	2000	17	21	26	33	41	51	63	77	94
	2200	22	27	33	41	50	61	74	90	108
	2400	29	36	43	52	63	76	90	108	128
	2600	40	47	57	68	81	96	114	135	160
	2800	54	65	77	92	109	129	152	180	211
	3000	76	91	109	130	155	185	220	261	309
	3200	110	136	167	205	251	308	376	459	
	3400	186	255	350	478					

Appendix E: Expected crash reduction rate – NZ

Facility	Expected Crash Reduction Δa
Platform	60%
Median Refuge	18%
Kerb Extensions (no zebra)	36%
Kerb Extensions at Zebra	44%
Kerb Extension and Median Refuge	32%
Zebra Platform	0.80
Traffic Signal	0.45

Appendix F: crash data from kano

FEDERAL ROAD SAFETY CORPS
POLICY, RESEARCH AND STATISTICS DEPARTMENT
RS1.2 SECTOR COMMAND KANO
SUMMARY OF ROAD TRAFFIC CRASHES INVOLVING VEHICLE(S) AND PEDESTRIAN FROM 2007-2014

S/N	COMMAND	FATAL	SERIOUS	MINOR	TOTAL CASES	NUMBER INJURED					NUMBER KILLED					TOTAL CASUALTY	PEOPLE INVOLVED					VEHICLE INVOLVED														VEHICLE CATEGORY				
						ADULT M	ADULT F	CHILD M	CHILD F	TOTAL	ADULT M	ADULT F	CHILD M	CHILD F	TOTAL		ADULT M	ADULT F	CHILD M	CHILD F	TOTAL	BICYCLE	MOTORCYCLE	TRICYCLE	CAR	SUV(JEEP)	VAN	MINIBUS	LUXURY BUS	PICK-UP	TRUCK	TANKER	TRAILER	OTHERS	TOTAL	PRIVATE	COMMERCIAL	GOVERNMENT	DIPLOMAT	TOTAL
1	RS1.2														2	0	0	7																						
		2	0	0	2	0	0	0	0	0	1	1	0	0	2	2	3	1	0	0	4	0	0	0	0	2	0	0	0	0	0	0	0	0	2	2	0	0	0	2
															2	0	0	8																						
		7	0	0	7	1	0	0	0	1	2	0	5	0	7	8	9	1	5	0	1	5	0	0	0	6	0	0	1	0	0	0	0	0	7	6	1	0	0	7
															2	0	0	9																						
		2	0	0	2	0	0	3	0	3	0	0	2	0	2	5	0	5	0	7	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2	2	0	0	0	2
															2	0	1	0																						
		3	15	4	22	69	20	1	3	93	8	1	2	0	11	104	92	27	4	3	126	0	13	0	5	1	0	5	0	1	0	0	0	0	24	9	15	0	0	24
															2	0	1	1																						
		7	10	0	17	59	29	13	12	113	16	0	0	0	16	129	143	60	17	17	254	0	1	0	5	1	0	6	2	1	1	0	0	0	17	9	8	0	0	17
															2	0	1	2																						
		2	14	0	16	48	6	14	2	40	6	0	3	0	9	49	44	10	14	3	71	0	9	1	7	0	1	4	0	0	0	0	0	0	21	8	13	0	0	21
															2	0	1	3																						
		4	29	3	36	65	26	6	2	99	7	0	0	0	7	106	155	42	16	9	222	2	8	2	7	0	1	11	0	3	1	0	1	1	36	2	34	0	0	36
																2	0	1	4																					
			18	0	28	44	12	0	5	64	15	1	0	0	16	75	95	28	1	27	93	0	6	0	1	1	0	10	0	0	1	0	0	0	28	9	12	2	0	28

CC MI GARBA
SECTOR COMANDER

Yearly Road Traffic Crash Report 2011 – 2014 covering Zaria Road, State Road, Maigwan township roads

Year	Number of people involved	People Injured	People Killed	Casualties
2011	12	5	0	5
2012	37	16	4	20
2013	23	8	1	9
2014	8	6	0	6

Vehicular speed limit in km/hour (source: Nigeria Highway code, 2013)

Types of Vehicles	Town and Cities	Highway	Express way
Motorcycles	50	50	
Private Cars	50	80	100
Taxis and Buses	50	80	90
Tankers and Trailers	45	50	60
Tow vehicles(while towing)	45	45	45
Tow vehicles(while not towing)	50	60	70

Appendix G: Java Program for pedestrian analytical delay computations

```
/**
 * @(#)AverageDelayPerPedestrian.java
 *
 *
 * @author
 * @version 1.00 2016/3/5
 */

import javax.swing.JOptionPane;
public class AverageDelayPerPedestrian {
        private static int vehicularFlowRatePerHour;

        private static final int START_UP_TIME = 2;
```

```
        private static final double PED_WALKING_SPEED = 1.2;
        private static final double SUM_OF_WIDTHS = 0.5;
        private static final int CROSS_WALK_LENGTH = 12;
        private static final double TOTAL_WALKWAY_WIDTH = 2.3;

    public AverageDelayPerPedestrian() {
    }

    public static double vehicularFlowRatePerSecond(int volume){
        return (double)volume / 3600.00;
    }

    public void setVehicularFlowRatePerHour(int volume){
        vehicularFlowRatePerHour = volume;
    }

    public static int getVehicularFlowRatePerHour(){
        return vehicularFlowRatePerHour;
    }

    public static double peak15FlowRate(){
        return (double)getVehicularFlowRatePerHour() / 4;
    }

    public static double calculateEffectiveCrossWalkWidth(){
        double effectiveCrossWalkWidth = TOTAL_WALKWAY_WIDTH -
SUM_OF_WIDTHS;
        return effectiveCrossWalkWidth;
    }
```

```
public static double calculateCriticalGap(){

        double criticalGap = ((double)CROSS_WALK_LENGTH /
PED_WALKING_SPEED) + START_UP_TIME;

        return criticalGap;

    }


    public static double calculatePedestrianFlowRate(){

        //return peak15FlowRate() / (15 * calculateEffectiveCrossWalkWidth());

        return 25.0 / (15 * calculateEffectiveCrossWalkWidth());

    }


    public static double calculateNumberOfPedestrian(){

        double totalNumberOfPedestrian = (((calculatePedestrianFlowRate() *
Math.exp(calculatePedestrianFlowRate() * calculateCriticalGap()))) +

                (vehicularFlowRatePerSecond(vehicularFlowRatePerHour) *
Math.exp(vehicularFlowRatePerSecond(vehicularFlowRatePerHour) *
calculateCriticalGap())))

                / ((calculatePedestrianFlowRate() +
vehicularFlowRatePerSecond(vehicularFlowRatePerHour)) *

                        Math.exp((calculatePedestrianFlowRate() -
vehicularFlowRatePerSecond(vehicularFlowRatePerHour)) * calculateCriticalGap()));

        return totalNumberOfPedestrian;

    }


    public static double calculateSpatialDistribution(){

        double spatialDistribution;

        spatialDistribution = ((int)((0.75 * (calculateNumberOfPedestrian() -
1))/(calculateEffectiveCrossWalkWidth()))) + 1;

        return spatialDistribution;

    }


    public static double getGroupCriticalPoint(){
```

```java
        double groupCriticalPoint = calculateCriticalGap() + (2 *
(calculateSpatialDistribution() - 1));

        return groupCriticalPoint;

    }


    public static double getAverageDelay(){

        double averageDelay = (1 /
vehicularFlowRatePerSecond(vehicularFlowRatePerHour)) *

                    ((Math.exp(vehicularFlowRatePerSecond(vehicularFlowRatePerHour)
* getGroupCriticalPoint())) -

                        (vehicularFlowRatePerSecond(vehicularFlowRatePerHour) *
getGroupCriticalPoint()) - 1);

        return Math.round(averageDelay * 100) / 100.0;

    }


    public String toString(){

        return String.format("%s :%.2fs",

                        "The average delay per pedestrian in a crosswalk is",
getAverageDelay());

    }


    public static void main(String[] args){

        AverageDelayPerPedestrian adp = new AverageDelayPerPedestrian();

        String flowRate = JOptionPane.showInputDialog("Enter the vehicular flow rate per
hour");

        int vehicularFlowRate = Integer.parseInt(flowRate);

        adp.setVehicularFlowRatePerHour(vehicularFlowRate);

        JOptionPane.showMessageDialog(null, "The average delay per pedestrian in a
crosswalk is: "+adp.getAverageDelay()+"s",

                                        "Average Delay Per Pedestrian",
JOptionPane.PLAIN_MESSAGE);

        //System.out.println(adp);    }

}
```

Appendix H: Signal Program In VISSIM (Sig codes)


```
<?xml version="1.0" encoding="UTF-8"?>

<sc version="201602" id="1" name="fuzzy intell" frequency="1" steps="0"
defaultIntergreenMatrix="0" interstagesUsingMinDurations="true"
checkSum="3329100132">

  <signaldisplays>

    <display id="1" name="Red" state="RED">

      <patterns>

        <pattern pattern="MINUS" color="#FF0000" isBold="true" />

      </patterns>

    </display>

    <display id="2" name="Red/Amber" state="REDAMBER">

      <patterns>

        <pattern pattern="FRAME" color="#CCCC00" isBold="true" />

        <pattern pattern="SLASH" color="#CC0000" isBold="false" />

        <pattern pattern="MINUS" color="#CC0000" isBold="false" />

      </patterns>

    </display>

    <display id="3" name="Green" state="GREEN">

      <patterns>

        <pattern pattern="FRAME" color="#00CC00" isBold="true" />

        <pattern pattern="SOLID" color="#00CC00" isBold="false" />

      </patterns>

    </display>

    <display id="4" name="Amber" state="AMBER">

      <patterns>

        <pattern pattern="FRAME" color="#CCCC00" isBold="true" />

        <pattern pattern="SLASH" color="#CCCC00" isBold="false" />
```

```
    </patterns>
  </display>
</signaldisplays>
<signalsequences>
  <signalsequence id="3" name="Red-Red/Amber-Green-Amber">
    <state display="1" isFixedDuration="false" isClosed="true" defaultDuration="1000" />
    <state display="2" isFixedDuration="true" isClosed="true" defaultDuration="1000" />
    <state display="3" isFixedDuration="false" isClosed="false" defaultDuration="5000" />
    <state display="4" isFixedDuration="true" isClosed="true" defaultDuration="3000" />
  </signalsequence>
</signalsequences>
<sgs>
  <sg id="1" name="Signal group 1" defaultSignalSequence="3">
    <defaultDurations>
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      <defaultDuration display="2" duration="1000" />
      <defaultDuration display="3" duration="5000" />
      <defaultDuration display="4" duration="3000" />
    </defaultDurations>
  </sg>
  <sg id="2" name="Signal group 2" defaultSignalSequence="3">
    <defaultDurations>
      <defaultDuration display="1" duration="1000" />
      <defaultDuration display="2" duration="1000" />
      <defaultDuration display="3" duration="5000" />
      <defaultDuration display="4" duration="3000" />
    </defaultDurations>
```

```
  </sg>
  <sg id="3" name="Signal group 3" defaultSignalSequence="3">
    <defaultDurations>
      <defaultDuration display="1" duration="1000" />
      <defaultDuration display="2" duration="1000" />
      <defaultDuration display="3" duration="5000" />
      <defaultDuration display="4" duration="3000" />
    </defaultDurations>
  </sg>
  <sg id="4" name="Signal group 4" defaultSignalSequence="3">
    <defaultDurations>
      <defaultDuration display="1" duration="1000" />
      <defaultDuration display="2" duration="1000" />
      <defaultDuration display="3" duration="5000" />
      <defaultDuration display="4" duration="3000" />
    </defaultDurations>
  </sg>
  <sg id="5" name="Signal group 5" defaultSignalSequence="3">
    <defaultDurations>
      <defaultDuration display="1" duration="1000" />
      <defaultDuration display="2" duration="1000" />
      <defaultDuration display="3" duration="5000" />
      <defaultDuration display="4" duration="3000" />
    </defaultDurations>
  </sg>
</sgs>
<intergreenmatrices>
```

```
  <intergreenmatrix id="1" name="Intergreen matrix 1">
    <intergreen clearingsg="4" enteringsg="1" value="7000" />
    <intergreen clearingsg="3" enteringsg="1" value="7000" />
    <intergreen clearingsg="1" enteringsg="3" value="7000" />
    <intergreen clearingsg="1" enteringsg="4" value="7000" />
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    <intergreen clearingsg="1" enteringsg="5" value="6000" />
    <intergreen clearingsg="3" enteringsg="5" value="6000" />
    <intergreen clearingsg="2" enteringsg="5" value="6000" />
    <intergreen clearingsg="5" enteringsg="2" value="6000" />
    <intergreen clearingsg="5" enteringsg="1" value="6000" />
  </intergreenmatrix>
</intergreenmatrices>
<progs>
  <prog id="1" cycletime="56000" switchpoint="0" offset="0" intergreens="1"
fitness="0.000000" vehicleCount="0" name="Signal program 1">
    <sgs>
      <sg sg_id="1" signal_sequence="3">
        <cmds>
          <cmd display="3" begin="5000" />
          <cmd display="1" begin="17000" />
        </cmds>
        <fixedstates>
          <fixedstate display="2" duration="1000" />
          <fixedstate display="4" duration="3000" />
        </fixedstates>
      </sg>
```

```
<sg sg_id="2" signal_sequence="3">
  <cmds>
    <cmd display="3" begin="3000" />
    <cmd display="1" begin="17000" />
  </cmds>
  <fixedstates>
    <fixedstate display="2" duration="1000" />
    <fixedstate display="4" duration="3000" />
  </fixedstates>
</sg>
<sg sg_id="3" signal_sequence="3">
  <cmds>
    <cmd display="1" begin="1000" />
    <cmd display="3" begin="39000" />
  </cmds>
  <fixedstates>
    <fixedstate display="4" duration="3000" />
    <fixedstate display="2" duration="1000" />
  </fixedstates>
</sg>
<sg sg_id="4" signal_sequence="3">
  <cmds>
    <cmd display="1" begin="0" />
    <cmd display="3" begin="38000" />
  </cmds>
  <fixedstates>
    <fixedstate display="2" duration="1000" />
```

```
        <fixedstate display="4" duration="3000" />
      </fixedstates>
    </sg>
    <sg sg_id="5" signal_sequence="3">
      <cmds>
        <cmd display="3" begin="21000" />
        <cmd display="1" begin="36000" />
      </cmds>
      <fixedstates>
        <fixedstate display="2" duration="1000" />
        <fixedstate display="4" duration="3000" />
      </fixedstates>
    </sg>
   </sgs>
  </prog>
 </progs>
 <stages />
 <interstageProgs />
 <stageProgs />
 <dailyProgLists />
</sc>
```

Appendix I: Program to generate sample signal time in MATLAB

```
clear

clc

%@-- PLEASE DEFINE THE DESIRED INPUT PARAMETERS TO GENERATE TRAFFIC OUTPUTS -@%

min_peddelay   =  0;

max_peddelay   =  300;

min_totalped   =  0;

max_totalped   =  120;

min_vqueue     =  0;

max_vqueue     =  50;

Ntrials        =  100;

%@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@

%@ NOTE: PLEASE YOU ARE NOT ALLOWED TO EDIT OR TEMPER WITH THE CODES BELOW

Data=gen_Vtraffic_data(min_peddelay,...

                    max_peddelay,...

                    min_totalped,...

                    max_totalped,...

                    min_vqueue,...

                    max_vqueue,Ntrials);

Fuzzy_Traffic_Controller=readfis('veh-pedcontrol-edited3');

Traffic_Signal_Delay=ceil(evalfis(Data,Fuzzy_Traffic_Controller)*10)/10;

disp('@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@')

 disp('---------------------INPUTS----------------------------------#@---OUTPUT-------');

 disp('| Trial | Peddelay    | Totalped   |Vehicles|  Weather | Green Light |');

 disp('|  No.  | (Seconds.) |   - -     | Queues |  Variable|   Duration  |');

 disp('------------------------------------- ------------------------------');
```

```
 for m =1:Ntrials
      fprintf(' %4g    ', m); fprintf('    %4g     ', Data(m,1));
      fprintf('      %4g     ', Data(m,2));fprintf('    %4g ', Data(m,3));
      fprintf('   %11.2f ', Data(m,4)); fprintf('   %11.1f ', Traffic_Signal_Delay(m));
      fprintf('\n');
 end
disp('@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@')


function Data=gen_Vtraffic_data(min_peddelay,...
                                 max_peddelay,...
                                 min_totalped,...
                                 max_totalped,...
                                 min_vqueue,...
                                 max_vqueue,Ntrials)
%@ Weader parameters is selected as a random value between zero and one
Data=[];
for Try=1:Ntrials
    peddelay=ceil(min_peddelay+rand*(max_peddelay-min_peddelay));
    totalped=ceil(min_totalped+rand*(max_totalped-min_totalped));
    vqueue=ceil(min_vqueue+rand*(max_vqueue-min_vqueue));
    Weather=ceil(rand*100)/100;
    Data=[Data;[peddelay,totalped,vqueue,Weather]];
end


---------------------INPUTS----------------------------------#@---OUTPUT-------
| Trial  | Peddelay    | Totalped   | Vehicles |   Weather  | Green Light  |
|  No.   | (Seconds.) |    - -     | Queues  |   Variable |    Duration   |
------------------------------------ -----------------------------
```

1	245	109	7	0.92	21.0
2	190	12	14	0.55	14.9
3	288	116	8	0.98	20.3
4	288	59	41	0.15	18.4
5	127	110	40	0.96	20.5
6	197	5	43	0.94	15.8
7	204	91	38	0.40	21.4
8	197	21	36	0.04	16.0
9	84	6	5	0.83	18.4
10	209	39	48	0.04	18.5
11	132	46	39	0.80	21.1
12	57	59	23	0.65	21.7
13	213	91	14	0.68	18.1
14	197	20	6	0.50	17.7
15	288	41	30	0.23	12.4
16	226	31	26	0.70	14.9
17	268	116	28	0.14	15.0
18	45	31	43	0.26	20.6
19	245	30	47	0.35	15.5
20	59	31	31	0.48	20.6
21	106	100	30	0.55	21.7
22	276	35	38	0.76	14.9
23	115	69	4	0.06	22.9
24	160	94	47	0.13	21.9
25	171	57	1	0.34	14.4
26	49	96	16	0.53	19.5
27	50	73	14	0.66	21.4
28	207	90	23	0.09	15.9
29	69	110	8	0.83	12.6

30	162	120	4	0.45	19.4
31	32	116	1	0.78	13.4
32	246	105	5	0.40	22.0
33	78	97	22	0.92	21.0
34	55	32	8	0.14	13.0
35	261	70	28	0.15	10.3
36	256	75	18	0.52	21.7
37	121	10	12	0.13	12.7
38	56	29	21	0.05	20.7
39	271	114	25	0.49	15.0
40	102	109	19	0.12	21.8
41	235	47	13	0.41	17.2
42	29	16	48	0.96	15.1
43	173	8	12	0.36	14.9
44	247	2	3	0.17	17.5
45	195	88	33	0.46	22.2
46	165	36	38	0.19	16.0
47	207	23	19	0.63	14.9
48	235	10	47	0.78	15.4
49	147	53	23	0.31	17.8
50	153	62	41	0.80	21.4
51	194	46	41	0.54	21.1
52	106	113	44	0.56	21.7
53	187	71	11	0.31	16.9
54	142	28	43	0.20	16.0
55	68	21	12	0.44	18.3
56	94	111	22	0.19	21.4
57	272	118	22	0.12	15.0
58	78	50	30	0.27	21.3

59	181	86	12	0.12	18.3
60	90	39	22	0.51	21.1
61	26	32	41	0.03	15.1
62	279	88	25	0.58	22.0
63	72	56	49	0.55	21.4
64	157	28	25	0.63	14.9
65	204	48	19	0.99	16.8
66	12	107	46	0.80	22.2
67	30	32	17	0.68	15.1
68	41	87	6	0.66	15.5
69	149	94	36	0.91	21.1
70	268	41	35	0.20	13.6
71	10	90	26	0.48	15.0
72	272	74	31	0.86	21.6
73	242	70	10	0.24	18.8
74	266	4	25	0.17	13.3
75	294	86	26	0.48	21.4
76	18	82	3	0.08	21.2
77	157	12	41	0.82	15.8
78	217	18	33	0.52	14.9
79	292	78	41	0.46	20.7
80	130	100	5	0.14	22.1
81	53	47	42	0.81	20.9
82	19	48	27	0.42	15.0
83	198	76	15	0.44	19.2
84	5	119	9	0.11	16.5
85	112	24	25	0.34	18.7
86	286	111	3	0.74	21.7
87	81	51	28	0.95	20.7

88	126	118	16	0.71	20.2
89	200	65	35	0.67	22.1
90	54	16	50	0.18	20.8
91	10	68	45	0.67	14.9
92	58	45	24	0.99	20.2
93	47	103	33	0.38	20.8
94	58	52	25	0.13	21.6
95	177	28	20	0.59	14.9
96	76	35	31	0.27	20.6
97	248	118	37	0.35	21.2
98	176	13	46	0.88	15.8
99	246	32	30	0.03	13.4
100	128	38	9	0.18	16.8

Appendix J: Sample Table of Vehicles in VISSIM Network

Table of vehicles entered

File: C:\Users\Public\Documents\PTV Vision\PTV Vissim 9\vehicle -ped signallised4.inpx

Comment:

Date: Monday, April 24, 2017 2:51:02 AM

PTV Vissim 9.00-05 [63828]

Time;	Link;	Lane;	VehNo;	VehType;	Line;	DesSpeed;
1.5;	1;	1;	1;	100;	0;	56.4;
5.1;	3;	1;	2;	100;	0;	51.0;
7.9;	3;	1;	3;	100;	0;	54.6;
8.8;	9;	1;	4;	100;	0;	54.6;
13.6;	1;	1;	5;	100;	0;	53.8;
15.9;	5;	1;	6;	520;	0;	5.9;
16.9;	9;	1;	7;	100;	0;	53.2;
20.5;	9;	1;	8;	100;	0;	57.1;
21.2;	12;	1;	9;	510;	0;	4.1;
21.9;	1;	1;	10;	100;	0;	49.6;
26.7;	3;	1;	11;	100;	0;	55.9;
28.6;	1;	1;	12;	100;	0;	50.8;
30.0;	12;	1;	13;	520;	0;	6.0;
31.1;	1;	1;	14;	100;	0;	50.9;
32.2;	4;	1;	15;	100;	0;	52.8;
37.0;	4;	1;	16;	100;	0;	49.5;
38.7;	4;	1;	17;	100;	0;	53.6;
43.2;	4;	1;	18;	100;	0;	48.7;
44.6;	10;	1;	19;	520;	0;	4.8;
47.1;	4;	1;	20;	100;	0;	57.6;
47.3;	12;	1;	21;	520;	0;	4.4;

47.7;	9;	1;	22;	100;	0;	49.0;
49.4;	3;	1;	23;	100;	0;	51.1;
50.7;	1;	1;	24;	100;	0;	54.8;
63.7;	9;	1;	25;	100;	0;	55.5;
64.5;	12;	1;	26;	520;	0;	4.9;
68.1;	1;	1;	27;	100;	0;	52.3;
69.7;	4;	1;	28;	100;	0;	57.6;
70.2;	3;	1;	30;	100;	0;	55.9;
72.1;	4;	1;	29;	100;	0;	49.2;
75.4;	4;	1;	31;	200;	0;	54.8;
76.0;	1;	1;	32;	100;	0;	53.9;
76.1;	7;	1;	33;	520;	0;	5.5;
84.8;	9;	1;	34;	100;	0;	49.8;
86.9;	11;	1;	35;	510;	0;	5.8;
90.3;	4;	1;	36;	100;	0;	56.1;
90.4;	9;	1;	37;	100;	0;	52.8;
90.9;	10;	1;	38;	520;	0;	5.6;
91.1;	1;	1;	39;	100;	0;	58.0;
94.5;	3;	1;	40;	100;	0;	53.7;
97.4;	9;	1;	41;	100;	0;	55.1;
106.1;	3;	1;	42;	100;	0;	56.2;
109.4;	4;	1;	43;	100;	0;	52.0;
111.0;	3;	1;	45;	100;	0;	55.6;
112.4;	9;	1;	46;	100;	0;	56.4;
112.6;	4;	1;	44;	100;	0;	51.6;
114.2;	1;	1;	47;	100;	0;	55.5;
121.8;	1;	1;	48;	100;	0;	53.0;
125.4;	6;	1;	49;	510;	0;	4.3;
125.6;	1;	1;	50;	100;	0;	53.0;

126.0;	3;	1;	51;	100;	0;	51.5;
127.2;	6;	1;	52;	510;	0;	4.2;
131.4;	1;	1;	53;	100;	0;	53.7;
133.3;	9;	1;	54;	100;	0;	56.3;
137.5;	9;	1;	55;	100;	0;	51.0;
139.0;	9;	1;	56;	100;	0;	56.3;
139.3;	4;	1;	57;	100;	0;	48.1;
140.5;	9;	1;	58;	100;	0;	51.2;
141.9;	9;	1;	59;	100;	0;	48.3;
143.2;	3;	1;	60;	100;	0;	52.0;
144.8;	8;	1;	61;	520;	0;	4.5;
149.2;	9;	1;	62;	200;	0;	54.8;
153.2;	1;	1;	63;	100;	0;	54.9;
158.5;	12;	1;	64;	520;	0;	4.0;
159.5;	12;	1;	65;	510;	0;	4.8;
163.4;	1;	1;	66;	100;	0;	57.4;
165.9;	1;	1;	67;	100;	0;	48.4;
170.7;	8;	1;	68;	510;	0;	5.5;
171.2;	4;	1;	69;	100;	0;	54.7;
171.4;	9;	1;	70;	100;	0;	53.2;
171.7;	1;	1;	71;	100;	0;	49.4;
174.0;	4;	1;	72;	100;	0;	48.3;
177.5;	9;	1;	73;	100;	0;	57.1;
178.7;	3;	1;	74;	100;	0;	52.7;
180.6;	4;	1;	75;	100;	0;	57.2;
182.6;	10;	1;	76;	520;	0;	5.0;
186.6;	1;	1;	77;	100;	0;	57.5;
186.7;	9;	1;	78;	100;	0;	55.3;
188.3;	7;	1;	79;	510;	0;	5.5;

193.1;	4;	1;	80;	100;	0;	53.3;
194.0;	3;	1;	81;	100;	0;	53.0;
197.2;	5;	1;	82;	520;	0;	4.3;
197.8;	4;	1;	83;	100;	0;	49.1;
198.2;	7;	1;	84;	510;	0;	4.3;
201.5;	1;	1;	85;	100;	0;	52.5;
202.9;	4;	1;	86;	100;	0;	51.7;
203.0;	6;	1;	87;	520;	0;	5.5;
203.5;	9;	1;	88;	100;	0;	53.6;
205.6;	10;	1;	89;	510;	0;	5.1;
207.5;	1;	1;	90;	100;	0;	49.9;
208.2;	9;	1;	91;	100;	0;	58.0;
208.6;	3;	1;	92;	100;	0;	53.9;
211.1;	1;	1;	93;	100;	0;	54.8;
212.2;	9;	1;	94;	100;	0;	50.1;
213.7;	3;	1;	95;	100;	0;	56.9;
217.6;	8;	1;	97;	520;	0;	5.3;
219.3;	3;	1;	98;	100;	0;	54.9;
222.3;	4;	1;	99;	100;	0;	51.6;
226.1;	4;	1;	100;	100;	0;	56.5;
226.7;	3;	1;	101;	100;	0;	52.4;
226.8;	7;	1;	102;	520;	0;	5.3;
230.0;	3;	1;	103;	100;	0;	48.8;
232.3;	3;	1;	104;	100;	0;	55.2;
232.4;	1;	1;	96;	100;	0;	55.0;
232.9;	4;	1;	106;	100;	0;	51.4;
234.0;	5;	1;	107;	510;	0;	4.7;
238.1;	6;	1;	108;	510;	0;	5.5;
239.8;	4;	1;	109;	100;	0;	49.0;

240.7;	1;	1;	105;	100;	0;	53.8;
241.1;	9;	1;	110;	100;	0;	53.2;
245.0;	1;	1;	112;	100;	0;	57.1;
254.6;	3;	1;	114;	100;	0;	50.0;
267.9;	9;	1;	116;	100;	0;	57.1;
269.1;	3;	1;	115;	100;	0;	57.0;
272.5;	3;	1;	117;	100;	0;	53.1;
273.6;	4;	1;	111;	100;	0;	57.6;
278.1;	4;	1;	118;	100;	0;	49.5;
278.4;	10;	1;	120;	520;	0;	5.4;
280.0;	6;	1;	121;	520;	0;	4.1;
282.8;	7;	1;	122;	520;	0;	5.2;
289.2;	4;	1;	119;	100;	0;	52.4;
292.5;	4;	1;	123;	100;	0;	48.0;
296.0;	9;	1;	124;	100;	0;	50.4;
307.7;	9;	1;	125;	100;	0;	50.5;
308.1;	1;	1;	113;	100;	0;	58.0;
309.0;	3;	1;	127;	100;	0;	55.8;
312.3;	1;	1;	126;	100;	0;	50.2;
313.7;	3;	1;	129;	100;	0;	56.6;
314.8;	9;	1;	130;	100;	0;	56.3;
318.7;	3;	1;	131;	100;	0;	57.3;
323.9;	1;	1;	128;	100;	0;	54.2;
325.9;	8;	1;	135;	520;	0;	4.4;
326.9;	9;	1;	136;	100;	0;	52.0;
335.4;	8;	1;	137;	510;	0;	5.7;
339.4;	11;	1;	138;	510;	0;	4.7;
340.1;	9;	1;	139;	100;	0;	55.9;
346.8;	3;	1;	133;	100;	0;	54.1;

347.5;	4;	1;	132;	100;	0;	48.4;
349.8;	3;	1;	140;	100;	0;	57.1;
350.8;	4;	1;	141;	100;	0;	53.2;
355.3;	2;	1;	144;	510;	0;	5.2;
358.6;	4;	1;	143;	100;	0;	49.0;
359.2;	3;	1;	142;	100;	0;	53.5;
360.9;	9;	1;	147;	100;	0;	55.5;
362.8;	3;	1;	146;	100;	0;	50.1;
369.1;	4;	1;	145;	100;	0;	48.7;
371.5;	9;	1;	150;	100;	0;	53.5;
378.0;	5;	1;	151;	520;	0;	5.9;
380.2;	1;	1;	134;	100;	0;	58.0;
383.1;	9;	1;	153;	100;	0;	52.1;
384.2;	1;	1;	152;	100;	0;	53.8;
392.1;	1;	1;	154;	100;	0;	50.4;
395.2;	9;	1;	156;	100;	0;	49.2;
416.0;	3;	1;	148;	100;	0;	48.9;
418.5;	4;	1;	149;	100;	0;	56.2;
420.9;	3;	1;	157;	100;	0;	55.4;
423.2;	4;	1;	158;	100;	0;	54.4;
428.7;	2;	1;	161;	510;	0;	4.9;
429.9;	3;	1;	159;	100;	0;	54.3;
430.2;	9;	1;	163;	100;	0;	52.3;
430.4;	4;	1;	160;	100;	0;	54.4;
433.6;	9;	1;	165;	100;	0;	57.1;
433.9;	3;	1;	162;	100;	0;	56.9;
435.3;	9;	1;	167;	100;	0;	54.5;
437.7;	12;	1;	168;	520;	0;	5.9;
439.1;	4;	1;	164;	100;	0;	52.4;

451.1;	1;	1;	155;	100;	0;	50.5;
452.8;	9;	1;	171;	100;	0;	52.2;
458.6;	1;	1;	170;	100;	0;	53.4;
459.8;	9;	1;	173;	100;	0;	52.9;
462.2;	1;	1;	172;	100;	0;	53.8;
472.3;	9;	1;	175;	100;	0;	53.6;
477.6;	6;	1;	176;	520;	0;	4.5;
480.0;	9;	1;	177;	100;	0;	48.5;
487.0;	9;	1;	178;	100;	0;	48.4;
488.2;	4;	1;	169;	100;	0;	53.6;
489.6;	3;	1;	166;	100;	0;	53.3;
493.1;	3;	1;	180;	100;	0;	56.1;
494.2;	4;	1;	179;	100;	0;	54.9;
496.0;	9;	1;	183;	100;	0;	56.1;
499.2;	9;	1;	184;	100;	0;	49.4;
502.0;	6;	1;	185;	510;	0;	4.5;
503.5;	4;	1;	182;	100;	0;	55.5;
503.5;	3;	1;	181;	100;	0;	52.8;
509.3;	4;	1;	186;	100;	0;	51.1;
512.5;	9;	1;	189;	100;	0;	56.8;
518.2;	4;	1;	188;	100;	0;	48.5;
521.4;	7;	1;	191;	520;	0;	4.1;
524.1;	1;	1;	174;	100;	0;	48.3;
527.8;	1;	1;	192;	100;	0;	55.4;
532.4;	6;	1;	194;	520;	0;	5.0;
533.0;	1;	1;	193;	100;	0;	50.3;
533.2;	9;	1;	196;	100;	0;	56.3;
546.3;	9;	1;	197;	100;	0;	52.4;
558.2;	3;	1;	187;	100;	0;	56.0;

562.6;	3;	1;	198;	100;	0;	54.5;
565.8;	4;	1;	190;	100;	0;	54.7;
566.9;	3;	1;	199;	100;	0;	53.1;
568.4;	9;	1;	202;	100;	0;	57.8;
569.7;	4;	1;	200;	100;	0;	51.6;
571.7;	9;	1;	204;	100;	0;	53.9;
574.0;	9;	1;	205;	100;	0;	57.3;
576.1;	3;	1;	201;	100;	0;	51.8;
579.8;	7;	1;	207;	510;	0;	4.5;
580.7;	4;	1;	203;	100;	0;	57.3;
584.6;	9;	1;	209;	100;	0;	57.5;
585.5;	4;	1;	208;	100;	0;	57.5;
594.2;	11;	1;	212;	510;	0;	4.1;
594.6;	10;	1;	213;	510;	0;	5.5;
595.9;	1;	1;	195;	100;	0;	50.0;
598.6;	7;	1;	215;	520;	0;	5.0;
599.6;	1;	1;	214;	100;	0;	50.4;

Appendix K: Sample Table of travel time

File: C:\Users\Public\Documents\PTV Vision\PTV Vissim 9\vehicle -ped signallised4.inpx

Comment:

Date: Monday, April 24, 2017 2:51:02 AM

PTV Vissim 9.00-05 [63828]

Time;	No.;	Veh;	VehType;	Trav.;	Delay.;	Dist;
43.6;	5;	6;	520;	27.0;	0.0;	44.2;
51.4;	13;	2;	100;	44.0;	35.4;	120.5;
52.2;	4;	15;	100;	17.2;	8.4;	127.6;
54.0;	10;	9;	510;	27.2;	0.0;	31.3;
57.8;	4;	16;	100;	19.4;	10.1;	127.6;
64.4;	13;	11;	100;	35.0;	27.2;	120.5;
64.9;	4;	17;	100;	25.0;	16.4;	127.6;
70.4;	13;	23;	100;	18.5;	9.9;	120.5;
70.7;	4;	18;	100;	24.9;	15.5;	127.6;
82.6;	3;	4;	100;	71.7;	52.8;	280.9;
86.6;	1;	1;	100;	84.8;	66.7;	283.2;
87.3;	3;	7;	100;	69.2;	50.1;	280.9;
93.2;	1;	5;	100;	79.2;	60.2;	283.2;
94.5;	3;	8;	100;	72.8;	55.0;	280.9;
101.2;	1;	10;	100;	79.0;	58.3;	283.2;
102.1;	3;	22;	100;	52.0;	31.2;	280.9;
105.6;	10;	13;	520;	71.7;	0.1;	31.3;
108.2;	7;	19;	520;	61.3;	0.1;	35.0;
110.0;	9;	33;	520;	31.6;	0.1;	41.9;
110.6;	11;	35;	510;	20.5;	0.0;	32.9;
110.9;	10;	21;	520;	58.5;	0.1;	31.3;

111.8; 10; 26; 520; 42.6; 0.1; 31.3;

115.6; 7; 38; 520; 22.7; 0.0; 35.0;

123.6; 4; 20; 100; 74.8; 66.8; 127.6;

129.8; 4; 28; 100; 57.8; 49.8; 127.6;

131.2; 13; 40; 100; 34.1; 25.9; 120.5;

136.1; 4; 29; 100; 62.3; 53.0; 127.6;

136.0; 13; 42; 100; 27.5; 19.7; 120.5;

144.4; 4; 31; 200; 67.2; 58.8; 127.6;

152.1; 3; 25; 100; 86.3; 68.1; 280.9;

159.4; 1; 12; 100; 130.5; 110.4; 283.2;

159.8; 3; 34; 100; 73.0; 52.7; 280.9;

165.6; 1; 14; 100; 134.4; 114.2; 283.2;

165.9; 3; 37; 100; 74.1; 55.0; 280.9;

170.9; 1; 24; 100; 119.6; 100.9; 283.2;

172.5; 3; 41; 100; 73.8; 55.4; 280.9;

183.4; 12; 49; 510; 55.4; 0.1; 35.9;

184.5; 12; 52; 510; 54.5; 0.1; 35.9;

185.2; 6; 61; 520; 37.8; 0.1; 34.5;

192.2; 10; 64; 520; 28.1; 0.0; 31.3;

193.1; 10; 65; 510; 28.0; 2.8; 31.3;

195.2; 6; 68; 510; 22.5; 0.0; 34.5;

196.2; 13; 51; 100; 67.9; 59.3; 120.5;

196.3; 4; 36; 100; 103.0; 94.7; 127.6;

201.2; 4; 43; 100; 88.7; 79.9; 127.6;

209.5; 4; 44; 100; 94.5; 85.5; 127.6;

209.7; 13; 74; 100; 28.5; 20.1; 120.5;

214.8; 13; 81; 100; 18.2; 9.9; 120.5;

216.0; 4; 57; 100; 73.6; 63.9; 127.6;

225.5; 3; 46; 100; 110.9; 92.7; 280.9;

231.4; 1; 27; 100; 162.8; 143.3; 283.2;

231.5; 3; 54; 100; 96.0; 78.0; 280.9;

236.7; 1; 32; 100; 160.4; 141.4; 283.2;

239.2; 3; 55; 100; 100.3; 80.4; 280.9;

243.8; 1; 39; 100; 152.2; 134.6; 283.2;

244.6; 3; 56; 100; 104.4; 86.5; 280.9;

251.3; 12; 87; 520; 46.0; 0.1; 35.9;

251.7; 7; 76; 520; 66.8; 0.1; 35.0;

252.5; 7; 89; 510; 44.8; 0.1; 35.0;

253.9; 6; 97; 520; 34.3; 0.1; 34.5;

254.3; 9; 79; 510; 63.8; 0.1; 41.9;

258.9; 5; 82; 520; 60.7; 0.1; 44.2;

259.8; 9; 84; 510; 58.8; 0.1; 41.9;

260.8; 9; 102; 520; 31.6; 2.1; 41.9;

263.7; 12; 108; 510; 23.4; 0.0; 35.9;

267.1; 13; 92; 100; 56.0; 47.9; 120.5;

267.9; 4; 69; 100; 93.7; 85.3; 127.6;

269.3; 5; 107; 510; 34.2; 0.0; 44.2;

274.0; 4; 72; 100; 98.1; 88.4; 127.6;

280.6; 4; 75; 100; 96.9; 88.8; 127.6;

287.0; 4; 80; 100; 90.5; 81.7; 127.6;

298.1; 3; 58; 100; 156.2; 136.5; 280.9;

302.4; 1; 47; 100; 187.5; 169.2; 283.2;

305.1; 3; 59; 100; 161.8; 140.8; 280.9;

309.3; 1; 48; 100; 187.0; 167.7; 283.2;

314.5; 3; 62; 200; 162.5; 144.0; 280.9;

315.5; 1; 50; 100; 189.6; 170.4; 283.2;

320.1; 3; 70; 100; 146.3; 127.3; 280.9;

322.6; 7; 120; 520; 42.1; 0.1; 35.0;

327.2; 9; 122; 520; 41.9; 0.1; 41.9;

328.3; 12; 121; 520; 45.5; 0.1; 35.9;

338.8; 13; 103; 100; 107.0; 98.2; 120.5;

339.9; 4; 83; 100; 138.7; 129.2; 127.6;

345.9; 4; 86; 100; 140.0; 131.0; 127.6;

351.7; 4; 99; 100; 126.2; 117.2; 127.6;

359.4; 4; 100; 100; 130.8; 122.6; 127.6;

363.0; 13; 115; 100; 87.7; 80.0; 120.5;

372.1; 3; 73; 100; 193.0; 175.2; 280.9;

374.4; 1; 53; 100; 242.4; 223.5; 283.2;

376.4; 3; 78; 100; 187.2; 168.9; 280.9;

381.8; 1; 63; 100; 227.9; 209.0; 283.2;

384.4; 3; 88; 100; 178.0; 159.0; 280.9;

387.0; 1; 66; 100; 223.3; 205.5; 283.2;

389.8; 3; 91; 100; 180.0; 162.5; 280.9;

398.2; 11; 138; 510; 55.1; 0.1; 32.9;

398.5; 8; 144; 510; 40.8; 0.1; 42.4;

401.8; 6; 135; 520; 73.4; 0.1; 34.5;

402.6; 6; 137; 510; 65.2; 0.1; 34.5;

405.9; 5; 151; 520; 27.0; 0.0; 44.2;

412.0; 4; 106; 100; 141.2; 132.2; 127.6;

418.5; 4; 109; 100; 141.5; 132.0; 127.6;

419.8; 13; 127; 100; 107.3; 99.5; 120.5;

425.2; 13; 129; 100; 82.8; 75.1; 120.5;

425.5; 4; 111; 100; 140.7; 132.7; 127.6;

431.3; 13; 131; 100; 84.4; 76.7; 120.5;

433.4; 4; 118; 100; 143.0; 133.7; 127.6;

443.0; 3; 94; 100; 229.0; 208.8; 280.9;

447.9; 1; 67; 100; 281.8; 260.7; 283.2;

448.6; 3; 110; 100; 204.9; 185.9; 280.9;

453.6; 1; 71; 100; 281.1; 260.5; 283.2;

455.8; 3; 116; 100; 185.0; 167.2; 280.9;

459.2; 1; 77; 100; 271.7; 253.8; 283.2;

463.5; 3; 124; 100; 164.6; 144.4; 280.9;

465.8; 10; 168; 520; 24.3; 0.1; 31.3;

471.8; 8; 161; 510; 40.5; 0.1; 42.4;

483.3; 13; 133; 100; 128.8; 120.7; 120.5;

484.2; 4; 119; 100; 139.1; 130.3; 127.6;

489.9; 4; 123; 100; 141.1; 131.4; 127.6;

496.5; 13; 142; 100; 84.8; 76.5; 120.5;

497.1; 4; 132; 100; 140.8; 131.2; 127.6;

503.4; 4; 141; 100; 137.0; 128.3; 127.6;

515.0; 3; 125; 100; 204.4; 184.4; 280.9;

519.4; 1; 85; 100; 316.9; 297.4; 283.2;

520.6; 3; 130; 100; 203.9; 185.7; 280.9;

526.0; 1; 90; 100; 317.4; 297.1; 283.2;

529.1; 3; 136; 100; 199.3; 179.6; 280.9;

531.5; 1; 93; 100; 319.7; 301.2; 283.2;

535.3; 3; 139; 100; 192.4; 174.1; 280.9;

542.3; 12; 176; 520; 62.2; 0.1; 35.9;

543.1; 12; 185; 510; 38.5; 0.1; 35.9;

555.8; 4; 143; 100; 138.9; 129.5; 127.6;

561.5; 9; 191; 520; 37.0; 0.0; 41.9;

563.0; 4; 145; 100; 141.0; 131.4; 127.6;

565.1; 13; 157; 100; 135.7; 127.7; 120.5;

567.9; 4; 149; 100; 138.5; 130.3; 127.6;

575.6; 4; 158; 100; 139.4; 130.8; 127.6;

577.6; 13; 162; 100; 87.6; 79.8; 120.5;

585.6;   3;   147;   100; 221.6; 203.2; 280.9;

590.9;   1;   96;   100; 357.2; 338.7; 283.2;

591.3;   3;   150;   100; 215.7; 196.8; 280.9;

597.0;   1;   105;   100; 354.9; 336.0; 283.2;

598.1;   3;   153;   100; 212.3; 193.0; 280.9;

Appendix L: Vissim Model Layout Code


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visible="true">

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sizeHeight="508" sizeWidth="154" subType="" tag="" text="" textTabResolved="" type=""
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								<objectRef key="1 1 3"/>

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isSelectedTab="true" keyText="Network Objects1" no="2" paneLayoutNo="0"
paneType="CONTROL" pinned="true" sizeHeight="486" sizeWidth="154" subType=""
tag="" text="Network Objects" textTabResolved="Network Objects"
type="PTV.Vision.Controls.MainWindowNetObjSelectionControl, Controls,
Version=9.0.5.0, Culture=neutral, PublicKeyToken=null" visible="true"/>

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flyoutSizeHeight="-1" flyoutSizeWidth="-1" isDirectAreaChild="false"
isSelectedTab="false" keyText="Levels1" no="3" paneLayoutNo="0"
paneType="CONTROL" pinned="true" sizeHeight="0" sizeWidth="0" subType="" tag=""
text="Levels" textTabResolved="Levels" type="PTV.Vision.Controls.LevelSelectionControl,
Controls, Version=9.0.5.0, Culture=neutral, PublicKeyToken=null" visible="true"/>

						<dockableChildPane childPaneStyle="0"
flyoutSizeHeight="-1" flyoutSizeWidth="-1" isDirectAreaChild="false"
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<dockableChildPane childPaneStyle="0" flyoutSizeHeight="-1" flyoutSizeWidth="-1" isDirectAreaChild="false" isSelectedTab="false" keyText="Smart Map1" no="7" paneLayoutNo="2" paneType="CONTROL" pinned="true" sizeHeight="0" sizeWidth="0" subType="" tag="" text="Smart Map" textTabResolved="Smart Map" type="PTV.Vision.Controls.SmartMapControl, ControlUtils, Version=9.0.5.0, Culture=neutral, PublicKeyToken=null" visible="true"/>

</dockChildPanes>

</dockableAreaPane>

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type="PTV.Vision.Controls.NetEditorControl, ControlUtils, Version=9.0.5.0, Culture=neutral, PublicKeyToken=null" visible="true"/>

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<dockableChildPane childPaneStyle="0" flyoutSizeHeight="-1" flyoutSizeWidth="-1" isDirectAreaChild="false" isSelectedTab="false" keyText="Static Vehicle Routes1" no="6" paneLayoutNo="7" paneType="CONTROL" pinned="true" sizeHeight="0" sizeWidth="0" subType="Parent VEHICLEROUTESTATIC" tag="" text="Static Vehicle Routes" textTabResolved="Static Vehicle Routes" type="PTV.Vision.Controls.CoupledListWindow, Controls, Version=9.0.5.0, Culture=neutral, PublicKeyToken=null" visible="true"/>

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<dockableChildPane childPaneStyle="0" flyoutSizeHeight="-1" flyoutSizeWidth="-1" isDirectAreaChild="false" isSelectedTab="false" keyText="Signal Controllers1" no="12" paneLayoutNo="15" paneType="CONTROL" pinned="true" sizeHeight="180" sizeWidth="1207" subType="Parent SIGNALCONTROLLER" tag="" text="Signal Controllers / Signal Groups" textTabResolved="Signal Controllers / Signal Groups" type="PTV.Vision.Controls.CoupledListWindow, Controls, Version=9.0.5.0, Culture=neutral, PublicKeyToken=null" visible="true"/>

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</dockChildPanes>

</dockableAreaPane>

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<defaultWindowLayouts>

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<windowLayoutDefault floating="false" height="96" no="8" positionX="179" positionY="1187" subType="Parent QUEUECOUNTER" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="198" no="9" positionX="179" positionY="983" subType="Parent DELAYMEASUREMENTEVALUATION" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="96" no="10" positionX="179" positionY="1187" subType="Parent SIGNALCONTROLLER" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="198" no="11" positionX="179" positionY="983" subType="Parent DELAYMEASUREMENT" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="96" no="12" positionX="179" positionY="1187" subType="Parent DATACOLLECTIONMEASUREMENT" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="198" no="13" positionX="179" positionY="983" subType="TIMEINTERVAL" type="ListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="96" no="14" positionX="179" positionY="1187" subType="Parent LINKBEHAVIORTYPE" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="96" no="15" positionX="179" positionY="1187" subType="Parent VEHICLEROUTINGDECISIONSTATIC" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="96" no="16" positionX="179" positionY="1187" subType="Parent VEHICLEINPUT" type="CoupledListWindow" width="1187"/>

<windowLayoutDefault floating="false" height="198" no="17" positionX="179" positionY="983" subType="Parent CONFLICTAREA" type="CoupledListWindow" width="1187"/>

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</defaultWindowLayouts>

<listLayouts>

<listLayout childRelation="VEHCOMPRELFLOWS" exportListWhenSimulationFinished="false" name="" no="2" verticalSplitterPosition="0.49130074565037285">

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<attributeListLayoutParameters alignment="LEFT" attributeID="DESSPEEDDISTR" columnWidth="88" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="RELFLOW" columnWidth="54" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

</attributeLPars>

</childNetObjectLParSet>

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="VEHICLECOMPOSITION" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="false">

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<attributeListLayoutParameters alignment="LEFT" attributeID="NAME" columnWidth="48" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="RELFLOW(100,50)" columnWidth="0" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>
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</attributeLPars>

</netObjectLParSet>

</listLayout>

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<attributeLPars>

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<attributeListLayoutParameters alignment="LEFT" attributeID="LEVEL" columnWidth="40" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="NUMLANES" columnWidth="70" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="LENGTH2D" columnWidth="64" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="CENTER" attributeID="ISCONN" columnWidth="50" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="FROMLINK" columnWidth="63" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="TOLINK" columnWidth="48" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

</attributeLPars>

</childNetObjectLParSet>

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="VEHICLEINPUT" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="true">

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<attributeListLayoutParameters alignment="LEFT" attributeID="VEHCOMP(1)" columnWidth="79" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

</attributeLPars>

</netObjectLParSet>

</listLayout>

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<childNetObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="LINK" rowHeaderWidth="0" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="true">

<attributeLPars>

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<attributeListLayoutParameters alignment="LEFT" attributeID="LEVEL" columnWidth="40" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="NUMLANES" columnWidth="70" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="LENGTH2D" columnWidth="64" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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</attributeLPars>

</childNetObjectLParSet>

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="VEHICLEROUTINGDECISIONSTATIC" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="false">

<attributeLPars>

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<attributeListLayoutParameters alignment="LEFT" attributeID="NAME" columnWidth="45" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="LINK" columnWidth="101" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="POS" columnWidth="67" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="CENTER" attributeID="ALLVEHTYPES" columnWidth="76" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="VEHCLASSES" columnWidth="70" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

</attributeLPars>

</netObjectLParSet>

</listLayout>

<listLayout childRelation="" exportListWhenSimulationFinished="false" name="" no="7" verticalSplitterPosition="0.5">

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="VEHICLEROUTESTATIC" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="true">

<attributeLPars>

<attributeListLayoutParameters alignment="LEFT" attributeID="VEHROUTDEC" columnWidth="77" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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<attributeListLayoutParameters alignment="LEFT" attributeID="NAME" columnWidth="45" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="DESTLINK" columnWidth="113" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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</attributeLPars>

</netObjectLParSet>

</listLayout>

<listLayout childRelation="" exportListWhenSimulationFinished="false" name="" no="8" verticalSplitterPosition="0.5">

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="VEHICLETRAVELTIMEMEASUREMENT" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="true">

<attributeLPars>

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<attributeListLayoutParameters alignment="LEFT" attributeID="STARTLINK" columnWidth="101" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="STARTPOS" columnWidth="67" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="ENDLINK" columnWidth="101" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="ENDPOS" columnWidth="67" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="DIST" columnWidth="67" decimals="2" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

</attributeLPars>

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</netObjectLParSet>

</listLayout>

<listLayout childRelation="" exportListWhenSimulationFinished="false"
name="" no="9" verticalSplitterPosition="0.5">

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netObjectTypeID="DELAYMEASUREMENT" rowHeaderWidth="35" rowHeight="0"
showSimulationRunAggregates="true" showTimeIntervalAggregates="false"
synchronization="false">

<attributeLPars>

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attributeID="NO" columnWidth="29" decimals="0" format="DEFAULT"
quickViewRowHeight="0" showUnits="false"/>

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attributeID="NAME" columnWidth="45" decimals="0" format="DEFAULT"
quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT"
attributeID="VEHTRAVTMMEAS" columnWidth="99" decimals="0" format="DEFAULT"
quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT"
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format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT"
attributeID="VEHDELAY(1,TOTAL,ALL)" columnWidth="0" decimals="2"
format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT"
attributeID="VEHDELAY(1,AVG,ALL)" columnWidth="0" decimals="2"
format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT"
attributeID="VEHDELAY(1,STDDEV,ALL)" columnWidth="0" decimals="2"
format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT"
attributeID="VEHDELAY(5,LAST,ALL)" columnWidth="0" decimals="2"
format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

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attributeID="VEHDELAY(5,TOTAL,ALL)" columnWidth="0" decimals="2"
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attributeID="VEHDELAY(5,AVG,ALL)" columnWidth="0" decimals="2"
format="SECONDS" quickViewRowHeight="0" showUnits="false"/>
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<attributeListLayoutParameters alignment="RIGHT" attributeID="VEHDELAY(5,STDDEV,ALL)" columnWidth="0" decimals="2" format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

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</attributeLPars>

</netObjectLParSet>

</listLayout>

<listLayout childRelation="" exportListWhenSimulationFinished="false" name="" no="11" verticalSplitterPosition="0.5">

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="CONFLICTAREA" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="true">

<attributeLPars>

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<attributeListLayoutParameters alignment="LEFT" attributeID="LINK2" columnWidth="113" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="VISIBLINK2" columnWidth="67" decimals="1" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="LEFT" attributeID="STATUS" columnWidth="86" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="FRONTGAPDEF" columnWidth="80" decimals="1" format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="REARGAPDEF" columnWidth="75" decimals="1" format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

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<attributeListLayoutParameters alignment="RIGHT" attributeID="SAFDISTFACTDEF" columnWidth="89" decimals="1" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="ADDSTOPDIST" columnWidth="79" decimals="1" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="CENTER" attributeID="OBSADJLNS" columnWidth="70" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="ANTICIPROUT" columnWidth="76" decimals="1" format="PERCENT" quickViewRowHeight="0" showUnits="true"/>

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</attributeLPars>

</netObjectLParSet>

</listLayout>

<listLayout childRelation="VEHCOMPRELFLOWS" exportListWhenSimulationFinished="false" name="" no="12" verticalSplitterPosition="0.48995983935742971">

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<attributeListLayoutParameters alignment="RIGHT" attributeID="RELFLOW" columnWidth="54" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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</childNetObjectLParSet>

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<attributeListLayoutParameters alignment="RIGHT" attributeID="RELFLOW(100,50)" columnWidth="0" decimals="3" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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</netObjectLParSet>

</listLayout>

<listLayout childRelation="SGS" exportListWhenSimulationFinished="false" name="" no="15" verticalSplitterPosition="0.4995857497928749">

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showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="false">

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</attributeLPars>

</childNetObjectLParSet>

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="SIGNALCONTROLLER" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="false">

<attributeLPars>

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</attributeLPars>

</netObjectLParSet>

</listLayout>

<listLayout childRelation="" exportListWhenSimulationFinished="false" name="" no="16" verticalSplitterPosition="0.5">

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<attributeLPars>

<attributeListLayoutParameters alignment="RIGHT" attributeID="START" columnWidth="0" decimals="1" format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

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</attributeLPars>

</netObjectLParSet>

</listLayout>

<listLayout childRelation="" exportListWhenSimulationFinished="false" name="" no="17" verticalSplitterPosition="0.5">

<netObjectLParSet filtered="false" headerHeight="0" netObjectTypeID="DELAYMEASUREMENTEVALUATION" rowHeaderWidth="35" rowHeight="0" showSimulationRunAggregates="true" showTimeIntervalAggregates="false" synchronization="false">

<attributeLPars>

<attributeListLayoutParameters alignment="LEFT" attributeID="SIMRUN" columnWidth="109" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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<attributeListLayoutParameters alignment="LEFT" attributeID="DELAYMEASUREMENT" columnWidth="143" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="STOPDELAY(ALL)" columnWidth="88" decimals="2" format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="STOPS(ALL)" columnWidth="64" decimals="2" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="VEHDELAY(ALL)" columnWidth="83" decimals="2" format="SECONDS" quickViewRowHeight="0" showUnits="false"/>

<attributeListLayoutParameters alignment="RIGHT" attributeID="VEHS(ALL)" columnWidth="59" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

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<attributeListLayoutParameters alignment="RIGHT" attributeID="PERS(ALL)" columnWidth="57" decimals="0" format="DEFAULT" quickViewRowHeight="0" showUnits="false"/>

</attributeLPars>

</netObjectLParSet>

</listLayout>

</listLayouts>

<networkEditorLayouts>

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<gParSet>

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mapType="DEFAULTMAPPROVIDER" mode3D="false" rubberbandColor="fff0f000" selectionColor="fff0f000" showCompass="false" showGrid="true" showLogo="false" showMap="true" showScale="true" showSimTmLabel="false" simTmLabelColor="ff000000" simTmLabelFontSize="20" simTmLabelOffset="15 30" simTmLabelPos="BOTTOMLEFT" wireframeMode="false">

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<logoOffsetInternal x="20" y="20"/>

<simTmLabelOffsetInternal x="15" y="30"/>

</baseGPars>

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</attributeLPars>

</netObjectListLayoutParameters>

</netObjectLPars>

</quickViewLayout>

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</layout>

Appendix M: Sample Fuzzy rules

Spreadsheet Rule Editor - RB1

#	IF totalped	peddelay	vqueue	weather	THEN DoS	signaltime
1	small	low	small	false	1.00	low
2	small	low	small	false	0.35	medium
3	small	low	small	false	0.26	high
4	small	low	small	true	0.63	low
5	small	low	small	true	0.82	medium
6	small	low	small	true	0.98	high
7	small	low	medium	false	0.79	low
8	small	low	medium	false	0.55	medium
9	small	low	medium	false	0.90	high
10	small	low	medium	true	0.02	low
11	small	low	medium	true	0.57	medium
12	small	low	medium	true	0.27	high
13	small	low	large	false	0.27	low
14	small	low	large	false	0.21	medium
15	small	low	large	false	0.41	high
16	small	low	large	true	0.72	low
17	small	low	large	true	0.47	medium
18	small	low	large	true	0.56	high
19	small	medium	small	false	0.84	low
20	small	medium	small	false	0.16	medium
21	small	medium	small	false	0.83	high
22	small	medium	small	true	0.16	low
23	small	medium	small	true	0.79	medium
24	small	medium	small	true	0.50	high
25	small	medium	medium	false	0.73	low
26	small	medium	medium	false	0.05	medium
27	small	medium	medium	false	0.20	high
28	small	medium	medium	true	0.38	low
29	small	medium	medium	true	0.47	medium
30	small	medium	medium	true	0.18	high

Spreadsheet Rule Editor - RB1

#	IF				THEN	
	totalped	peddelay	vqueue	weather	DoS	signaltime
31	small	medium	large	false	0.15	low
32	small	medium	large	false	0.33	medium
33	small	medium	large	false	0.93	high
34	small	medium	large	true	0.09	low
35	small	medium	large	true	0.99	medium
36	small	medium	large	true	0.75	high
37	small	high	small	false	0.67	low
38	small	high	small	false	0.20	medium
39	small	high	small	false	0.63	high
40	small	high	small	true	0.09	low
41	small	high	small	true	0.64	medium
42	small	high	small	true	0.36	high
43	small	high	medium	false	0.94	low
44	small	high	medium	false	0.86	medium
45	small	high	medium	false	0.13	high
46	small	high	medium	true	0.60	low
47	small	high	medium	true	0.62	medium
48	small	high	medium	true	0.96	high
49	small	high	large	false	0.09	low
50	small	high	large	false	0.75	medium
51	small	high	large	false	0.65	high
52	small	high	large	true	0.84	low
53	small	high	large	true	0.61	medium
54	small	high	large	true	0.72	high
55	medium	low	small	false	0.28	low
56	medium	low	small	false	0.03	medium
57	medium	low	small	false	0.50	high
58	medium	low	small	true	0.25	low
59	medium	low	small	true	0.16	medium
60	medium	low	small	true	0.68	high

Spreadsheet Rule Editor - RB1

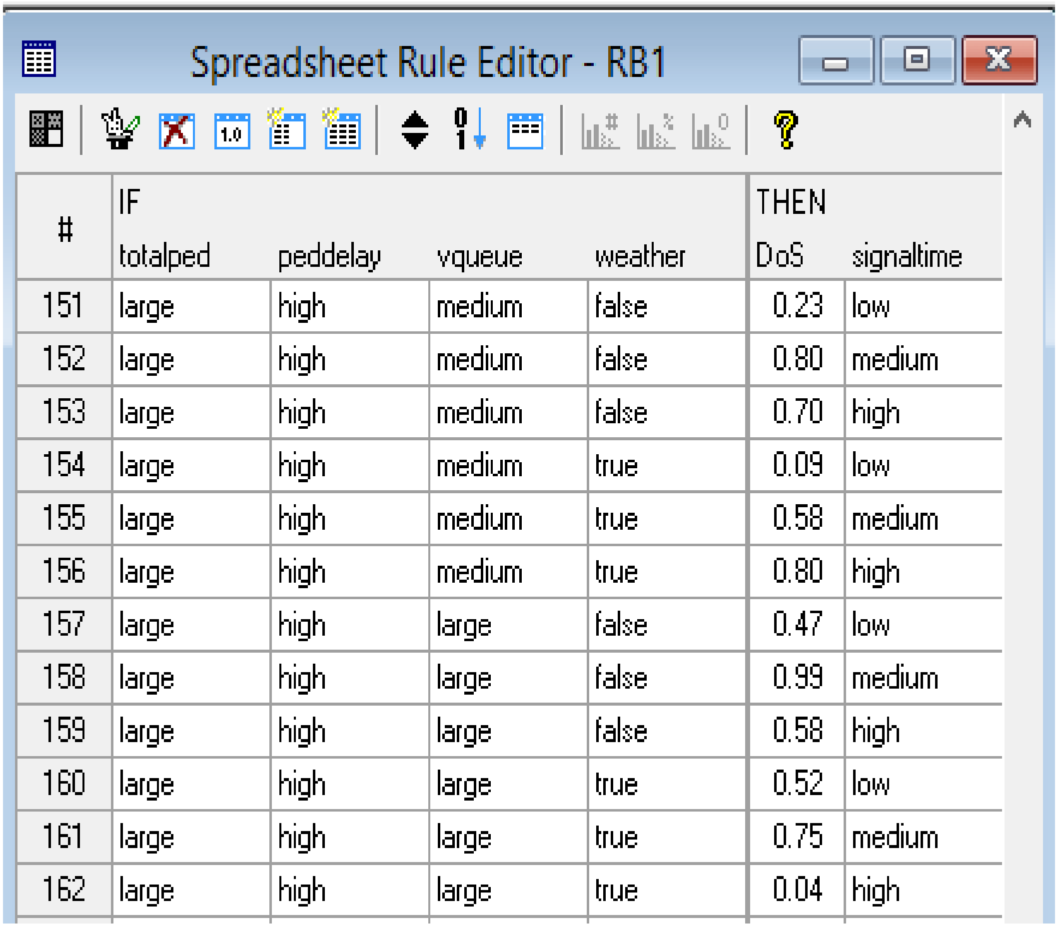
#	IF totalped	peddelay	vqueue	weather	THEN DoS	signaltime
61	medium	low	medium	false	0.88	low
62	medium	low	medium	false	0.97	medium
63	medium	low	medium	false	0.13	high
64	medium	low	medium	true	0.39	low
65	medium	low	medium	true	0.65	medium
66	medium	low	medium	true	0.35	high
67	medium	low	large	false	0.58	low
68	medium	low	large	false	0.22	medium
69	medium	low	large	false	0.80	high
70	medium	low	large	true	0.62	low
71	medium	low	large	true	0.77	medium
72	medium	low	large	true	0.96	high
73	medium	medium	small	false	0.48	low
74	medium	medium	small	false	0.12	medium
75	medium	medium	small	false	0.95	high
76	medium	medium	small	true	0.73	low
77	medium	medium	small	true	0.55	medium
78	medium	medium	small	true	0.16	high
79	medium	medium	medium	false	0.81	low
80	medium	medium	medium	false	0.87	medium
81	medium	medium	medium	false	0.90	high
82	medium	medium	medium	true	0.89	low
83	medium	medium	medium	true	0.09	medium
84	medium	medium	medium	true	0.16	high
85	medium	medium	large	false	0.93	low
86	medium	medium	large	false	0.28	medium
87	medium	medium	large	false	0.77	high
88	medium	medium	large	true	0.52	low
89	medium	medium	large	true	0.66	medium
90	medium	medium	large	true	0.59	high

Spreadsheet Rule Editor - RB1

#	IF totalped	peddelay	vqueue	weather	THEN DoS	signaltime
91	medium	high	small	false	0.71	low
92	medium	high	small	false	0.96	medium
93	medium	high	small	false	0.84	high
94	medium	high	small	true	0.56	low
95	medium	high	small	true	0.27	medium
96	medium	high	small	true	0.21	high
97	medium	high	medium	false	0.38	low
98	medium	high	medium	false	0.67	medium
99	medium	high	medium	false	0.59	high
100	medium	high	medium	true	0.58	low
101	medium	high	medium	true	0.82	medium
102	medium	high	medium	true	0.65	high
103	medium	high	large	false	0.23	low
104	medium	high	large	false	0.49	medium
105	medium	high	large	false	0.70	high
106	medium	high	large	true	0.66	low
107	medium	high	large	true	0.80	medium
108	medium	high	large	true	0.52	high
109	large	low	small	false	0.84	low
110	large	low	small	false	0.20	medium
111	large	low	small	false	0.22	high
112	large	low	small	true	0.98	low
113	large	low	small	true	0.51	medium
114	large	low	small	true	0.38	high
115	large	low	medium	false	0.24	low
116	large	low	medium	false	0.11	medium
117	large	low	medium	false	0.05	high
118	large	low	medium	true	0.36	low
119	large	low	medium	true	1.00	medium
120	large	low	medium	true	0.96	high

Spreadsheet Rule Editor - RB1

#	IF totalped	peddelay	vqueue	weather	THEN DoS	signaltime
121	large	low	large	false	0.40	low
122	large	low	large	false	0.77	medium
123	large	low	large	false	0.10	high
124	large	low	large	true	0.83	low
125	large	low	large	true	0.79	medium
126	large	low	large	true	0.88	high
127	large	medium	small	false	0.08	low
128	large	medium	small	false	0.54	medium
129	large	medium	small	false	0.16	high
130	large	medium	small	true	0.27	low
131	large	medium	small	true	0.60	medium
132	large	medium	small	true	0.28	high
133	large	medium	medium	false	0.63	low
134	large	medium	medium	false	0.88	medium
135	large	medium	medium	false	0.48	high
136	large	medium	medium	true	0.40	low
137	large	medium	medium	true	0.39	medium
138	large	medium	medium	true	0.98	high
139	large	medium	large	false	0.73	low
140	large	medium	large	false	0.78	medium
141	large	medium	large	false	0.59	high
142	large	medium	large	true	0.25	low
143	large	medium	large	true	0.62	medium
144	large	medium	large	true	0.24	high
145	large	high	small	false	0.32	low
146	large	high	small	false	0.26	medium
147	large	high	small	false	0.22	high
148	large	high	small	true	0.60	low
149	large	high	small	true	0.52	medium
150	large	high	small	true	0.62	high



#	IF totalped	peddelay	vqueue	weather	THEN DoS	signaltime
151	large	high	medium	false	0.23	low
152	large	high	medium	false	0.80	medium
153	large	high	medium	false	0.70	high
154	large	high	medium	true	0.09	low
155	large	high	medium	true	0.58	medium
156	large	high	medium	true	0.80	high
157	large	high	large	false	0.47	low
158	large	high	large	false	0.99	medium
159	large	high	large	false	0.58	high
160	large	high	large	true	0.52	low
161	large	high	large	true	0.75	medium
162	large	high	large	true	0.04	high

Appendix N: Travel time and delay measurement

Date: Wednesday, May 24, 2017 12:40:44 PM

PTV Vissim 8.00-13 [62094]

Time; No.; Veh;VehType; Trav.;Delay.;

36.5; 5; 2; 520; 33.6; 8.2;

36.4; 7; 6; 520; 26.0; 0.0;

39.4; 10; 3; 510; 30.0; 0.0;

39.4; 11; 12; 510; 20.5; 0.0;

41.2; 7; 13; 520; 22.7; 0.0;

41.1; 10; 4; 520; 30.1; 6.3;

42.5; 10; 7; 520; 28.7; 2.1;

43.2; 9; 11; 520; 27.2; 0.0;

43.9; 10; 9; 520; 27.5; 2.2;

48.2; 13; 5; 200; 38.4; 29.7;

56.5; 6; 18; 520; 27.7; 0.0;

77.6; 3; 10; 100; 62.3; 43.4;

78.8; 13; 31; 610; 34.7; 4.1;

86.7; 3; 17; 200; 59.5; 40.3;

87.5; 1; 1; 200; 85.0; 66.7;

94.3; 3; 21; 200; 62.1; 44.3;

107.5; 7; 24; 520; 72.1; 46.3;

109.0; 7; 29; 510; 69.4; 0.0;

Appendix O: VISSIM COM Interface Program in MATLAB

```
clear all;
close all;
clc;
%=================================================================
=========
% MATLAB-Script for Vissim 8+
%
% % - - - - - - - - - - - - - - - - - -
% This script is to connect to Vissim 8 64 bit, load the inpx file and
% layx, override the signal controller with fuzzy controller, run the simulation and the
evaluation.
%=================================================================
=========



%% Connecting the COM Server => Open a new Vissim Window:
Vissim = actxserver('Vissim.Vissim-64.800');
access_path=cd

%% Load a Vissim Network:
Vissim.LoadNet('C:\Users\Public\Documents\PTV Vision\PTV Vissim 8\Examples
Training\COM\Basic Commands\vehicle -ped signallised6.inpx');

%% Load a Layout:
Vissim.LoadLayout('C:\Users\Public\Documents\PTV Vision\PTV Vissim 8\Examples
Training\COM\Basic Commands\vehicle -ped signallised6.layx');


%%
=================================================================
======
% Read and Set attributes
%=================================================================
=========
% Note: All of the following commands can also be executed during a
% simulation.

% Set a signal controller program:
%SC_number = 1; % SC = SignalController
%SignalController = Vissim.Net.SignalControllers.ItemByKey(SC_number);
%new_signal_programm_number = 2;
%set(SignalController, 'AttValue', 'ProgNo', new_signal_programm_number);
%% Define the network object
vnet=Vissim.Net;
% The signal controller should be defined through Vissim-COM SignalControllers collection
scs=vnet.SignalControllers
sc=scs.ItemByKey(1); %(Signal Controller 1)
```

```
%sc_2=scs.ItemByKey(2); %(Signal Controller 2)
%sc_3=scs.ItemByKey(3); %(Signal Controller 3)
%sc_4=scs.ItemByKey(4); %(Signal Controller 4)
%sc_5=scs.ItemByKey(5); %(Signal Controller 5)
%sc_6=scs.ItemByKey(6); %(Signal Controller 6)
%sc_7=scs.ItemByKey(7); %(Signal Controller 7)
%sc_8=scs.ItemByKey(8); %(Signal Controller 8)

% Create signal group objects through SignalGroups collection:
sgs=sc.SGs

sg_1=sgs. ItemByKey (1) %(Signal Group 1)
sg_2=sgs. ItemByKey (2) %(Signal Group 2)
sg_3=sgs. ItemByKey (3) %(Signal Group 3)
sg_4=sgs. ItemByKey (4) %(Signal Group 4)
sg_5=sgs. ItemByKey (5) %(Signal Group 5)

% define a loop detector object for traffic demand sensing:
dets=sc.Detectors
det_all=dets.GetAll %(All detectors are queried first)
det_1=det_all{1}; %(The first detector of the detectors)
%det_2=det_all{2}; %(The second detector of the detectors)
%det_3=det_all{3}; %(The third detector of the detectors)
%det_4=det_all{4}; %(The fourth detector of the detectors)

%% Access to DataCollectionPoint object
datapoints=vnet.DataCollectionMeasurements
datapoint1=datapoints.ItemByKey(1)
datapoint2=datapoints.ItemByKey(2)
%% Set Simulation setting
sim=Vissim.Simulation;
%period_time=3600;
period_time=1200;
sim.set('AttValue', 'SimPeriod', period_time);
step_time=3;
sim.set('AttValue', 'SimRes', step_time);


%%
==================================================================
======
% Simulation
%==================================================================
=========

% Chose Random Seed
Random_Seed = 42;
set(Vissim.Simulation, 'AttValue', 'RandSeed', Random_Seed);

% To start a simulation you can run a single step:
```

```
%Vissim.Simulation.RunSingleStep;

% Or run the simulation continuous (it stops at breakpoint or end of simulation)
End_of_simulation = 1800; % simulation second [s]
set(Vissim.Simulation, 'AttValue', 'SimPeriod', End_of_simulation);
Sim_break_at = 200; % simulation second [s]
set(Vissim.Simulation, 'AttValue', 'SimBreakAt', Sim_break_at);
% Set maximum speed:
set(Vissim.Simulation, 'AttValue', 'UseMaxSimSpeed', true);
% Hint: to change the speed use: set(Vissim.Simulation, 'AttValue', 'SimSpeed', 10); % 10 =>
10 Sim. sec. / s
Vissim.Simulation.RunContinuous;

% First Attempt: Accessing all Attributes directly using "GetMultiAttValues" (fast)
disp('  Veh_No  |Veh_Type | Veh_Speed | Veh_Postn  | Veh_Lane  | Veh_Delay  |');
veh_numbers     = Vissim.Net.Vehicles.GetMultiAttValues('No');      % Output 1.
column:consecutive number; 2. column: AttValue
veh_types       = Vissim.Net.Vehicles.GetMultiAttValues('VehType'); % Output 1.
column:consecutive number; 2. column: AttValue
veh_speeds      = Vissim.Net.Vehicles.GetMultiAttValues('Speed');   % Output 1.
column:consecutive number; 2. column: AttValue
veh_positions   = Vissim.Net.Vehicles.GetMultiAttValues('Pos');     % Output 1.
column:consecutive number; 2. column: AttValue
veh_linklanes   = Vissim.Net.Vehicles.GetMultiAttValues('Lane');    % Output 1.
column:consecutive number; 2. column: AttValue
veh_delay       = Vissim.Net.Vehicles.GetMultiAttValues('DelayTm');
disp([veh_numbers(:,2), veh_types(:,2), veh_speeds(:,2), veh_positions(:,2),
veh_linklanes(:,2), veh_delay(:,2) ]) % only display the 2nd column

% To stop the simulation:
Vissim.Simulation.Stop;


%% Import the data
%data2.xlsx must be in MATLAB FOLDER plus this file and the other function for this code
to run
data2 = xlsread('C:\Users\TOLU\Documents\MATLAB\data2.xlsx','out1');

%% Clear temporary variables
clearvars raw;

fismat = genfis1(data2);
showfis(fismat);

%%
==================================================================
======
% Access during simulation
%=================================================================
=========
```

```
% Note: All of commands of "Read and Set attributes (vehicles)" can also be executed during
a
% simulation (e.g. changing signal controller program, setting relative flow of a static vehicle
route,
% changing the vehicle input, changing the vehicle composition).

%Sim_break_at = 198; % simulation second [s]
%set(Vissim.Simulation, 'AttValue', 'SimBreakAt', Sim_break_at);
%Vissim.Simulation.RunContinuous; % Start the simulation until SimBreakAt (198s)


% Get the state of a signal head:
SH_number = 1; % SH = SignalHead
State_of_SH = get(Vissim.Net.SignalHeads.ItemByKey(SH_number), 'AttValue', 'SigState');
% possible output e.g. 'GREEN', 'RED', 'AMBER', 'REDAMBER'
disp(['Actual state of SignalHead(',num2str(SH_number),') is:',32,State_of_SH]) % char(32)
is whitespace

% Set the state of a signal controller:
% Note: Once a state of a signal group is set, the attribute "ContrByCOM" is automatically
set to True.
% Meaning the signal group will keep this state until another state is set by COM or the end
of the simulation
% To switch back to the defined signal controller, set the attribute signal "ContrByCOM" to
False (example see below).
SC_number = 1; % SC = SignalController
SG_number = 1; % SG = SignalGroup
SignalController = Vissim.Net.SignalControllers.ItemByKey(SC_number);
SignalGroup = SignalController.SGs.ItemByKey(SG_number);
%new_state = 'GREEN'; %possible values e.g. 'GREEN', 'RED', 'AMBER', 'REDAMBER'
%set(SignalGroup, 'AttValue', 'SigState', new_state);
% Note: The signal controller can only be called at whole simulation seconds, so the state
will be set in Vissim
% at the next whole simulation second, here 199s
% Simulate so that the new state is active in the Vissim simulation:
%Sim_break_at = 200; % simulation second [s]
%set(Vissim.Simulation, 'AttValue', 'SimBreakAt', Sim_break_at);
%Vissim.Simulation.RunContinuous; % Start the simulation until SimBreakAt (200s)
%% Access to Link object
links=vnet.Links;
link_1=links.ItemByKey(1);
link_2=links.ItemByKey(2);
link_3=links.ItemByKey(3);
link_4=links.ItemByKey(4);

% Running the simulation with overriding through COM
%verify=20; % verifying at every 20 seconds
verify=20; % verifying at every 20 seconds

%Evaluation\Configuration...\Interval in the Vissim GUI
```

```
for i=0:(period_time*step_time)
sim.RunSingleStep;
if rem(i/step_time, verify)==0 % verifying at every 20 seconds
demand=det_1.get('AttValue', 'Presence'); %get detector occupancy:0/1
if demand==1 % demand -> demand-actuated stage
% major roads green (3), % pedestrian links red (1)
sg_1.set('AttValue', 'State', 3); %  green (3)
sg_2.set('AttValue', 'State', 3);
sg_3.set('AttValue', 'State', 1); % red(1)
sg_4.set('AttValue', 'State', 1); % red (1)
sg_5.set('AttValue', 'State', 1); % red (1)

else % no demand on loop ->  road's signal is green

%sg_1.set('AttValue', 'State', 3); %green (3)
%sg_2.set('AttValue', 'State', 1); % red (1)
sg_1.set('AttValue', 'State', 1); %  red(1)
sg_2.set('AttValue', 'State', 1);
sg_3.set('AttValue', 'State', 1);
sg_4.set('AttValue', 'State', 1);
sg_5.set('AttValue', 'State', 3);
end


end
end


% Give the control back:
%set(SignalGroup, 'AttValue', 'ContrByCOM', false);

% Query the avg. speed and vehicle number at the end of each eval. interval:


% Information about all vehicles in the network (in the current simulation second):

% Method : Accessing all Attributes directly using "GetMultiAttValues" (fast)
disp('  Veh_No  |Veh_Type | Veh_Speed | Veh_Postn  | Veh_Lane  | Veh_Delay  |');
veh_numbers     = Vissim.Net.Vehicles.GetMultiAttValues('No');      % Output 1.
column:consecutive number; 2. column: AttValue
veh_types       = Vissim.Net.Vehicles.GetMultiAttValues('VehType'); % Output 1.
column:consecutive number; 2. column: AttValue
veh_speeds      = Vissim.Net.Vehicles.GetMultiAttValues('Speed');   % Output 1.
column:consecutive number; 2. column: AttValue
veh_positions   = Vissim.Net.Vehicles.GetMultiAttValues('Pos');     % Output 1.
column:consecutive number; 2. column: AttValue
veh_linklanes   = Vissim.Net.Vehicles.GetMultiAttValues('Lane');    % Output 1.
column:consecutive number; 2. column: AttValue
veh_delay       = Vissim.Net.Vehicles.GetMultiAttValues('DelayTm');
```

```
disp([veh_numbers(:,2), veh_types(:,2), veh_speeds(:,2), veh_positions(:,2),
veh_linklanes(:,2), veh_delay(:,2) ]) % only display the 2nd column

% Continue the simulation until end of simulation (get(Vissim.Simulation, 'AttValue',
'SimPeriod'))
%Vissim.Simulation.RunContinuous;


%%
==================================================================
======
% Results of Simulations:
%==================================================================
=========


% Data Collection
DC_measurement_number = 1;
DC_measurement =
Vissim.Net.DataCollectionMeasurements.ItemByKey(DC_measurement_number);
%Syntax to get the data:
%  get(DC_measurement, 'AttValue', 'Vehs(sub_attribut_1, sub_attribut_2, sub_attribut_3)');
%
% sub_attribut_1: SimulationRun (same as described at Vehicle Travel Time Measurements)
% sub_attribut_2: TimeInterval  (same as described at Vehicle Travel Time Measurements)
% sub_attribut_3: VehicleClass  (same as described at Vehicle Travel Time Measurements)
%
% The value of on time interval is the arithmetic mean of all single values of the vehicles.

% Average value of all simulations (1. input = Avg)
%   of the 1st time interval (2. input = 1)
%   of all vehicle classes (3. input = All)
No_Veh         = get(DC_measurement, 'AttValue', 'Vehs        (Avg,1,All)'); % number of
vehicles
Speed          = get(DC_measurement, 'AttValue', 'Speed       (Avg,1,All)'); % Speed of
vehicles
Acceleration    = get(DC_measurement, 'AttValue', 'Acceleration(Avg,1,All)'); %
Acceleration of vehicles
Length         = get(DC_measurement, 'AttValue', 'Length      (Avg,1,All)'); % Length of
vehicles
disp(['Data Collection #',num2str(DC_measurement_number),': Average values of all
Simulations runs of 1st time interval of all vehicle classes:'])
disp(['#Vehicles:',32,num2str(No_Veh),'; Speed:',32,num2str(Speed),';
Acceleration:',32,num2str(Acceleration),'; Length:',32,num2str(Length)]) % char(32) is
whitespace
disp(' ');
disp(' ');
% Query the avg. speed and vehicle number at the end of each eval. interval:
%datapoint1.get('AttValue', 'Vehs(Current, Last, All)')
%datapoint1.get('AttValue', 'Speed(Current, Last, All)')
```

```
%datapoint1.get('AttValue', 'QueueDelay(Current, Last, All)')
%datapoint2.get('AttValue', 'Vehs(Current, Last, All)')
%datapoint2.get('AttValue', 'Speed(Current, Last, All)')
%datapoint2.get('AttValue', 'QueueDelay(Current, Last, All)')
%disp([veh_numbers(:,2), veh_types(:,2), veh_speeds(:,2), veh_positions(:,2),
veh_linklanes(:,2), veh_delay(:,2) ]) % only display the 2nd column

% Queue length
% Syntax to get the data:
%   get(QueueCounter, 'AttValue', 'QLen(sub_attribut_1, sub_attribut_2)');
%
% sub_attribut_1: SimulationRun (same as described at Vehicle Travel Time Measurements)
% sub_attribut_2: TimeInterval  (same as described at Vehicle Travel Time Measurements)
%

% Example #1:
% Average value of all simulations (1. input = Avg)
%   of the average of all time intervals (2. input = Avg)
QC_number = 1;
maxQ = get(Vissim.Net.QueueCounters.ItemByKey(QC_number),'AttValue',
'QLenMax(Avg, Avg)');
disp(['Average maximum Queue length of all simulations and time intervals of Queue
Counter #',num2str(QC_number),':',32,num2str(maxQ)]) % char(32) is whitespace


%%
=================================================================
======
% Saving
%=================================================================
=========
%Filename = fullfile(Path_of_COM_Basic_Commands_network, 'vehicle -ped signallised6
saved.inpx');
%Vissim.SaveNetAs(Filename)
%Filename = fullfile(Path_of_COM_Basic_Commands_network, 'vehicle -ped signallised6
saved.layx');
%Vissim.SaveLayout(Filename)


%%
=================================================================
======
% End Vissim
%=================================================================
=========
%Vissim.release
```

Appendix P: Crash Records From Colodora Department of Transport

COLORADO
Department of Transportation
Transportation Systems
Management & Operations

Colorado Fatalities by Person Type (2002-2017)

Year	Drivers (Age≥65)		Drivers (Age<65)		Passengers		Motorcycles		Pedestrians		Bicycles		Total	Reduction Rate
	Fatalities	% of Total	Fatalities	% of Total	Fatalities	% of Total	Fatalities	% of Total	Fatalities	% of Total	Fatalities	% of Total		
2002	56	7.5%	351	47.2%	183	24.6%	73	9.8%	71	9.6%	9	1.2%	743	N/A
2003	47	7.3%	288	44.9%	172	26.8%	70	10.9%	62	9.7%	3	0.5%	642	-13.6%
2004	46	6.9%	279	41.8%	180	27.0%	81	12.1%	70	10.5%	11	1.6%	667	3.9%
2005	39	6.4%	275	45.4%	148	24.4%	87	14.4%	49	8.1%	8	1.3%	606	-9.1%
2006	34	6.4%	236	44.1%	120	22.4%	74	13.8%	61	11.4%	10	1.9%	535	-11.7%
2007	42	7.6%	226	40.8%	125	22.6%	90	16.2%	60	10.8%	11	2.0%	554	3.6%
2008	47	8.6%	226	41.2%	118	21.5%	98	17.9%	47	8.6%	12	2.2%	548	-1.1%
2009	43	9.2%	191	41.1%	82	17.6%	88	18.9%	51	11.0%	10	2.2%	465	-15.1%
2010	40	8.9%	182	40.4%	98	21.8%	82	18.2%	40	8.9%	8	1.8%	450	-3.2%
2011	33	7.4%	195	43.6%	86	19.2%	78	17.4%	47	10.5%	8	1.8%	447	-0.7%
2012	37	7.8%	176	37.1%	91	19.2%	79	16.7%	78	16.5%	13	2.7%	474	6.0%
2013	46	9.6%	189	39.3%	95	19.8%	87	18.1%	52	10.8%	12	2.5%	481	1.5%
2014	38	7.8%	189	38.7%	92	18.9%	94	19.3%	65	13.3%	10	2.0%	488	1.5%
2015	49	9.0%	214	39.1%	101	18.5%	105	19.2%	64	11.7%	14	2.6%	547	13.7%
2016*	57	9.4%	219	36.0%	107	17.6%	125	20.6%	84	13.8%	16	2.6%	608	26.4%
2017**	39	7.9%	203	41.2%	92	18.7%	85	17.2%	61	12.4%	13	2.6%	493	1.0%