



**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF GRADUATE STUDIES**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**DEVELOPMENT OF MODELS OF INTERRUPTED TRAFFIC FLOW CONDITIONS  
OF ADDIS ABABA FROM A STUDY OF AN URBAN MULTI-LANE HIGHWAY**

By:

**Kidus Ayalneh Admasu**

*B.Sc. (Civil Engineering, Addis Ababa University, 2014)*

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of  
the Requirements for the Degree of

Master of Science

In

Road and Transport Engineering

Advisor:

**Bikila Teklu Wodajo (PhD)**

November, 2016

Addis Ababa, Ethiopia

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## UNDERTAKING

I, the undersigned, certify that this research work titled “*Development of Models of Interrupted Traffic Flow Conditions of Addis Ababa from a Study of an Urban Multi-lane Highway*” is my original work performed under the supervision of my research advisor *Dr. Bikila Teklu* and has not been presented elsewhere for assessment and for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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*Place of Undertaking:* Addis Ababa, Ethiopia.

*Date:* November, 2016

## ABSTRACT

Congestion problems in metropolitan areas are not addressed only through infrastructure measures. Capital cities of developing countries like Ethiopia are existing witnesses in supporting such premises. Thus, in assisting the collective effort in alleviating congestion problems, investigation of contributing factors that have been taking role in the interruptions of smooth traffic flow states have got due attention of this research. Thus, several scholars who have researched in the area revealed that the interruptions are of two pair of types: fixed & non-fixed on facility, and recurrent & non-recurrent while the contributing factors are behavioral issues associated with pedestrian movement characteristics & drivers' decision behaviors.

Moreover, among the seven types of modeling of traffic flow states and transport engineering parameters, this research adopted Strategic/Statistical Modeling in capturing recurrent as well as both fixed and non-fixed interruptions on facilities. And in addition to the modeling and condition types selected, this research took a multi-characteristics urban multi-lane highway with considerable variation in traffic, pedestrian characteristics and drivers behavior. Then, validation studies were conducted on two other random locations in Addis Ababa and the study outcomes were recommended with few limitations.

Finally, the results were interpreted and the key research findings were presented in three types. That is: statistical models, quantitatively captured behavioral parameters and inter-relationships among several captured parameters. And upon recommending for future use in research and practice, the 23 types of results were evident to be replicable to other analogous locations in Addis Ababa while other 3 are strongly stressed by the researcher that they shall remain to the study area. They are: pedestrian crossing speeds, pedestrian crossing patterns and the relationship between demand flow rate and saturation flow rate.

**KEY WORDS:** CHARACTERISTICS, BEHAVIOR, MODEL, FLOW, STATE, INTERRUPTION, DECISION, DRIVER, PEDESTRIAN, TRAFFIC, STABLE AND UNSTABLE

## ACKNOWLEDGEMENTS

First and foremost, I will like to say “*Thank you very much and there is no way that I can pay the good things that you invested in me!*” to my family, especially *my parents*. You are my heroes. Second in line, it is my great pleasure to forward my deepest gratitude to my *research advisor Dr. Bikila Teklu* for he has been a good mentor. I have enjoyed his support and kindness very well in that my research was a success.

Thirdly, I will like to thank *administrators and owners of buildings* along my study road segment in that they gave me permission to take videos. With their kindness, I was able to capture classic perspectives of the flow stream. And to mention names, they are: *Mr. Kidanu (Yeka Sub-city Admin. Bldg), Mr. Sitotaw (Sholla Division, First Instance Court Bldg), Dr. Emebet (Menarol Bldg) and Mr. Yidnek (Kebena Area Bldg)*.

Fourthly, I will like to thank *students of Addis Ababa Institute of Technology*, who helped me to shoot video recordings simultaneously on a day, at different locations. I salute their patience. They are: *Mr. Bahgi, Mr. Henok, Ms. Metasebia & Ms. Lidya*.

Fifthly, I will like to thank *Mr. Paul Mboya, PTV Group Representative for Eastern and Southern Africa* for his contribution in that I was handed *VISSIM 9 software (the student version)* for verifying my models. And sixthly, I will like to thank *pedestrians that responded to the attitude survey*, I prepared.

The last but not the least, I will like to thank the *Ethiopian Roads Authority (ERA)* for funding my graduate study of *Road and Transport Engineering* stream at the *Addis Ababa University*. I am very grateful and I appreciate.

## Dedication

To my mother, Sira Dagnachew Wubetie  
*(For her unconditional love and care)*

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## LIST OF ABBREVIATIONS AND ACRONYMS

LOS - Level of Service  
RA - Roundabout  
T - T Shaped Cross Intersection  
Xcs - Characteristics  
Vd - Demand Flow Rate  
Qsat - Saturation Flow Rate  
V - Speed  
L - Length  
t - Time Taken  
 $\mu$  - Mean  
 $\sigma$  - Standard Deviation  
 $\varepsilon$  - Error in Estimate  
Z - Statistical Table Value  
CI - Confidence Interval  
Inters. - Intersection  
LN - Lane  
k - Density  
U - Speed  
q - Flow  
Sec. - Section  
VISSIM - Software Name in Simulation of Traffic  
PTV - name of company that owns VISSIM  
NCHRP - National Cooperative Highway Research Program  
TRB - Transportation Research Board  
FHWA - Federal Highway Association  
DOT - Department of Transportation  
Admin. - Administration  
Bldg - Building  
PAS - Principal Arterial Street  
AACRA - Addis Ababa City Roads Authority  
ML - Mainline  
FG - Frontage  
LT - Left Turning  
TH - Through Movement  
RT - Right Turning  
Veh - Vehicle  
Pc - Passenger Car  
Km - Kilometers

## CHAPTER ONE: *INTRODUCTION*

### 1.1. General Background

Most metropolitan areas in the world are experiencing traffic congestion during commuting hours. *(David Schrank et al, 2012)* <sup>[1]</sup> This can be resolved by infrastructure expansions. However, new roads or widening existing ones requires more land, and expansion costs are high. Moreover, such solutions may not be feasible in metropolitan areas because of lack of space or for a harmful effect on the environment. In addition, once roads are expanded and congestion is resolved, population will move from congested areas to less congested ones, and thus traffic demand for the latter will increase, which will in turn cause congestion again. *(Dongyan Su, 2014)* <sup>[2]</sup>

The above global issue looks for a serious concern from urban management professionals and decision makers. To alleviate the congestion on urban roads, it is appropriate to address the problem through rational management measures. *(B. Maitra, 2004)* <sup>[3]</sup>

Particularly focusing on the capital city of Ethiopia, Addis Ababa City's road network comprises of 842 Km of asphalt concrete road out of which 344 Km is arterial, 116 Km is sub-arterial, 174 Km is collector and the remaining 208 Km is local roads. And from the above set, the local roads are of fair condition whilst the *hierarchy above* serves in *good to very good conditions*. *(Assegid Getachew, 2010)* <sup>[4]</sup>

And from 2010 on to this date, construction, rehabilitation and maintenance of roads in the network have *continued to increase the coverage*. Nonetheless, even though transportation facilities are being introduced in the belief that capacity will be enhanced, *severe peak hour congestion issues continued to affect road users*. This fact looks for the study of other *contributing factors*. Moreover, without due consideration of such factors, basic actions have shown to be ineffective.

With this regard, broad researches conducted by different scholars reveal the above contributing factors interrupting traffic to be majorly: *Incidents, Driver's Behavior and Pedestrian Characteristics*. *(Michael J. Markowski, 2008)* <sup>[5]</sup>

Thus, traffic operations on roadways can be improved by field research and field experiments of real-life traffic flow. Due to the complexity of the traffic flow

system, analytical approaches may not provide the desired results. Therefore, models designed to characterize the behavior of the complex traffic flow system have become an essential tool in analysis and experimentation. (Serge P. Hoogendoorn, 2001) [6]

## 1.2. Motivation

Several studied traffic management measures, in the objective of alleviating delay and other congestion problems here in Addis Ababa, did not prove to be adequate and/or efficient. And not only this, several reports made in such regard revealed that there are gaps in representing Addis Ababa's typical values of several parameters of the traffic flow. In addition, the aforementioned contributing factors to the congestion and reduced speed in flow streams remain hardly studied to this date. Thus, the researcher of this paper would like to contribute in filling the observed potential gaps present in research and practice.

## 1.3. Statement of the Problem

Even though insignificant numbers of vehicles operate on the road network of Addis Ababa, as compared to the developed nations, severe peak hour congestions exist. And apparent from the capacity issues that can be related to over saturated flow states, the human factor contributes significantly.

Thus, quantifying the effects and development of applicable and replicable models of interrupted flow conditions or states of Addis Ababa from collected data is essential in enabling anyone in identifying congestion problems (*that is caused by augmented contribution of transport facility and the human factor*) and reach at reliable solution measures.

## 1.4. Research Challenges

Studying interrupted traffic flow conditions and working on replicable models is a difficult task for obvious reasons. The following were the major challenges:

- ✚ In the task to address the overall stretch with ***simultaneous video recording at six locations for six hours***, the management was tedious.
- ✚ It was challenging to ***get the willingness of rushing pedestrians*** for an attitude survey.
- ✚ In order ***to make the models serve wet and dry conditions***, video recording was also made on rain conditions
- ✚ For a ***total video length of 48 hours and for separate 26 data types to capture***, the researcher consumed enormous time to derive tables and observations. And it was done by the researcher only in assuring the data quality.

## 1.5. Research Hypothesis and Questions

### 1.5.1. Hypothesis

By development of *statistical models of interrupted traffic flow states (unstable and stable)* of Addis Ababa for from a statistically verified and quality wise assured data, we can arrive at a viewpoint that enables us to look at the *contributing factors* and the *typical parameter values* of congestion states of the city.

### 1.5.2. Research Questions

- ✚ Which of the interruptions in the city induce major congestion problems of the road facilities?
- ✚ How can we quantify effects of irrational driver's behavior and pedestrian characteristics?
- ✚ What does the validation study reveal with regard to the models that are presented to be replicable?
- ✚ List and enumerate the typical parameter values of flow condition states of Addis Ababa that can be used for granted on other researches?
- ✚ How did the research adopt the pedestrian attitude survey results in modeling pedestrian characteristics?

## 1.6. Objectives of the Study

The research aims to make an interpretation of interrupted traffic flow states and to make a demonstration of modeling of interrupted flow conditions of Addis Ababa in general from a specific study of an urban multi-lane highway containing several types of intersections, flow conditions and operations.

The detail objectives are presented here under in general and specific.

### 1.6.1. General Objectives

The general objectives of the research are:

- ✚ To *contribute to the overall combined effort* towards the minimization of congestion issues on roadway facilities of the city Addis Ababa
- ✚ To *investigate behavioral factors* which induce congestion problems in transportation facilities in Addis Ababa

### 1.6.2. Specific Objectives

The specific objectives of the research are:

- ✚ To develop *models* of interrupted traffic flow states of Addis Ababa
- ✚ To come up with *saturation flow rates* that represent Addis Ababa's condition
- ✚ To demonstrate drivers' reaction to occurring *incidents and flow obstructions* in the study corridor.
- ✚ To draw *fundamental curves & trajectories* of pedestrians in the study corridor.

- ✚ To demonstrate *time space diagrams* of interrupted traffic states in the study corridor.
- ✚ To demonstrate *pedestrian characteristics* as derived from movement observations and attitude survey responses at Diaspora Roundabout.
- ✚ To study on *drivers' behavior in roundabouts, lane changing, acceleration-deceleration issues & aggressiveness* to incidents in the corridor flow stream.

## **1.7. Research Scope**

The scope of the study covers interrupted flow condition models of the city Addis Ababa, by a study extrapolated from a multi-lane highway incorporating different states and conditions. The validation of the models and parameter values is made using random highway facilities in the city.

The limitations and further researches that can be extended from this study will be directed in the Conclusion and Recommendations chapter (i.e. *Chapter Seven*).

### **1.7.1. Focus on Congestion in Addis Ababa**

Congestion in Addis Ababa's streets and intersections is affecting road users' life. As a result, it has got the attention of academicians, practitioners and traffic management offices in making enormous efforts to alleviate the problem. Thus, this research aims to share academicians' role in solving the problem.

### **1.7.2. Focus on Behaviors and Interruption Effects in Addis Ababa**

As it was explained in *Section 1.2*, behaviors and interruption effects remain to be unstudied and it is believed by the researcher that these contributing factors are controlling variables in modeling interrupted traffic states in Addis Ababa.

### **1.7.3. Focus on the Flow States and Interruptions on Comoros Street**

The strategically selected Comoros Street in Addis Ababa was picked by the researcher as ideal for the presence of several flow states and conditions, as described in detail in *Section 3.2*.

## **1.8. Contribution to the State-of-the-Art**

This research strives to describe the interruption to traffic flow streams in road segments and at intersections in a capital city in a developing country. In addition, no traffic flow model incorporating drivers' behavior and pedestrian characteristics issues specifically developed for or calibrated for a country like Ethiopia could be found yet. As a result, *this research is potential in contributing to the State-of-the-Art of interrupted traffic flow conditions in developing countries.*

## 1.9. Thesis Organization

This research is basically divided into seven main chapters. **Chapter one** intends to introduce the *underlying background science to the topic and the intended purposes* in doing the research. The **second chapter** extends the effort to look on background science in detail by *reviewing vast materials* in the area. The **third one** defines the *materials and methods* that was followed. **Fourthly**, the *data* collected from the study area is presented summarized in Tables. Then in **Chapter Five**, the *results and models* are presented. In the **sixth chapter**, *interpretation and validation study* will be presented and lastly in **Chapter Seven**, the *General objectives get their directives* and it marks the end of the research.

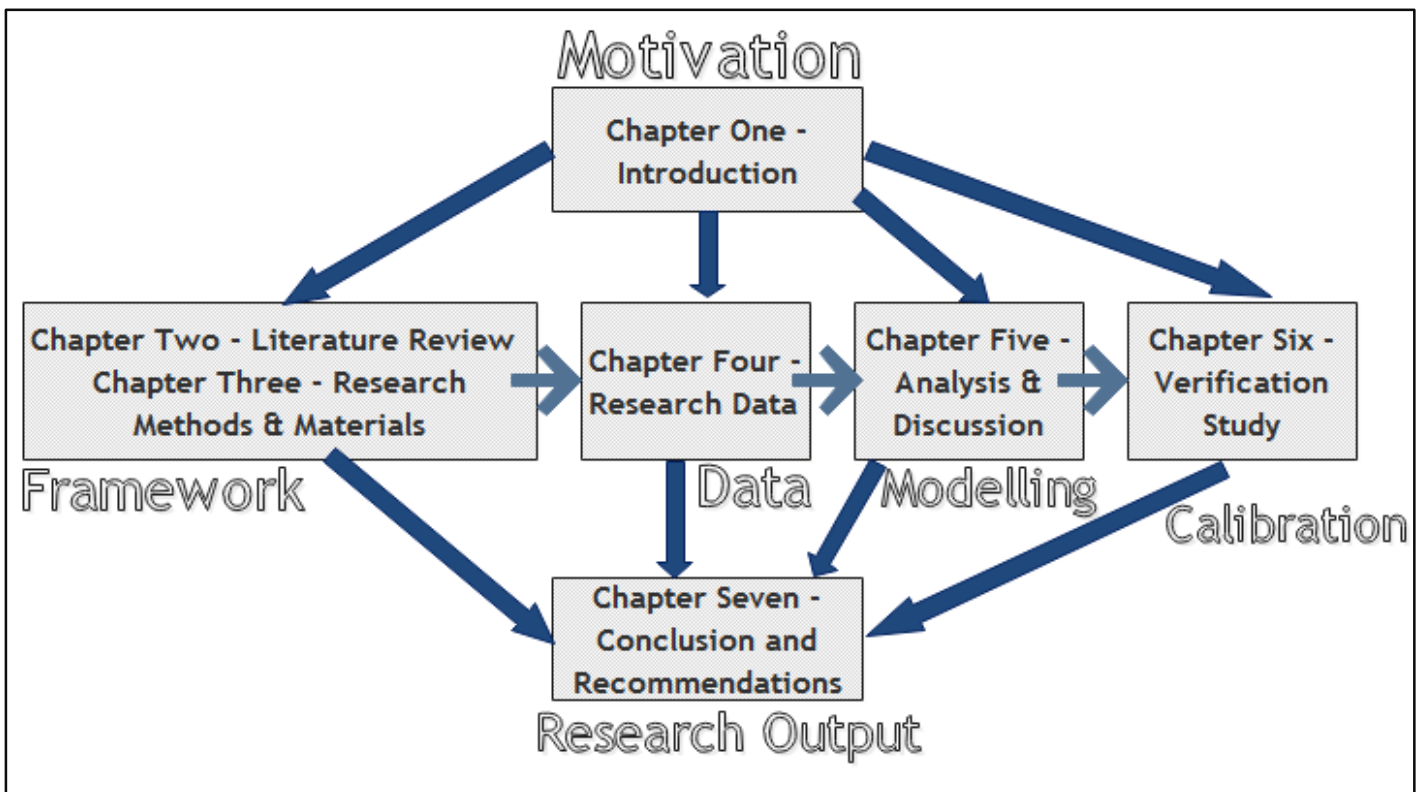


Figure 1.1: Thesis Organization Flow Chart

## CHAPTER TWO: *LITERATURE REVIEW*

### 2.1. Chapter Introduction

This chapter intends to look on several literatures written in the areas that the scope of this research is concerned about. **Section 2.2** will be discussing about Traffic Flow Study historical and current backgrounds. And since all traffic flow states are not operating in smooth conditions only, in **Section 2.3**, it is tried to discuss interrupted and uninterrupted traffic flow states. Moving on, since it is a good practice to represent real time conditions with representative and replicable models for future use in science and practice, the research paradigm in Traffic Flow Modeling is presented in **Section 2.4**. Congestion is intrigued not only because of demand and service capacity related issues but by the presence of certain behaviors of road users. This initiated the motive in reviewing necessary material on Pedestrian Characteristics and Drivers' Behavior in **Sections 2.5** and **2.6**, respectively.

Furthermore, city and metropolitan level modeling was studied in **Section 2.7**. And in **Section 2.8**, modeling software are compared for their relevance to this research objectives and **VISSIM 9.0** software was selected for a test in **Chapter 6**.

### 2.2. Traffic Flow Study

#### 2.2.1. Historical Background

Traffic has been extensively studied since the beginning of the 20<sup>th</sup> century. And with the advent of enormous automobiles, increasing number of vehicles began to filter onto the road infrastructure in the United States. This resulted in increase of congestion problems. And from the 1920's through 1950's, several researchers attempted to model these new phenomena. Based on these initial traffic models, new research field emerged and continues to this day. (**Scott Miller, 2011**) [7]

Traffic engineering got its roots as a rather practical discipline, entailing most of the time a common sense of its practitioners to solve particular traffic problems. However, all this changed at the dawn of the 1950s, when the scientific field began to mature, attracting engineers from all sorts of trades. Most notably, **John Glen Wardrop** instigated the evolving discipline now known as **traffic flow theory**, by describing traffic flows using mathematical and statistical ideas. (**Sven Maerivoet and Bart De Moor, 2008**) [8]

### **2.2.2. Types of Traffic Flow Studies**

The scientific field of traffic engineering encompasses a rich set of mathematical techniques, as well as researchers with entirely different backgrounds. According to *(Sven Maerivoet and Bart De Moor, 2008)*, it is a good practice to introduce four types of traffic flow study. They are: the *microscopic* and *macroscopic characteristics* of vehicular traffic flows, review on some *performance indicators* that allow us to assess the quality of traffic operations relations between *traffic flow characteristics*, i.e., the fundamental diagrams. *(Sven Maerivoet and Bart De Moor, 2008)* [8]

And according to *(NCHRP, Report 765, 2014)*, *Traffic Forecasting and Travel Demand Modeling* shall get due attention, especially when dealing with studying of the inception of road transport projects. Thus, creating project-level forecasts and for post-processing travel demand model results for use in the planning and design of highway projects, are tool boxes of techniques in guiding manuals. *(NCHRP, Report 765, 2014)* [9]

### **2.2.3. Data Requirements**

Many manuals provide guidance for the allocation and distribution of traffic counting points along the national road network. This is done in order to maintain consistency and attainment of appropriate comparisons of data between counting stations.

From traffic counts observations at different locations, it has been noticed that manual counts may be prone to increased human error when the number of enumerators are increased commensurate with increasing traffic flow. *(Botswana Guideline 9, 2004)* [10]

In most cases, information for traffic study is generally obtained by passive observation and measurement, without making direct contact with road users or directly interfering with traffic flows. Technological developments in data acquisition and analysis are facilitating the efficiency and effectiveness of passive observation methods. *(Austroads, 2013)* [11]

### **2.2.4. Congestion Studies**

Congestions in developing countries are triggered by a high travel demand, chaotic traffic behavior and a low supply of networks and means. The lack of adequate and accessible transport options causes a high share of non-motorized transport. This stressed mobility situation in developing countries results in premature congestion, a deteriorating environment and a high accident rate. *(K. Gwilliam, 2003)* [12]

The effects of road traffic congestion are visible on the economy, infrastructures, environment and health. The actual economic impacts of traffic congestion can

differ from one area to other, depending on its economic profile and business location pattern. On the other hand, reduced social interaction is a cost of congestion as people are discouraged from social trips due to increased travel time. Congested routes also attract raised transport fare. (Kayode Olagunju, 2015) [13]

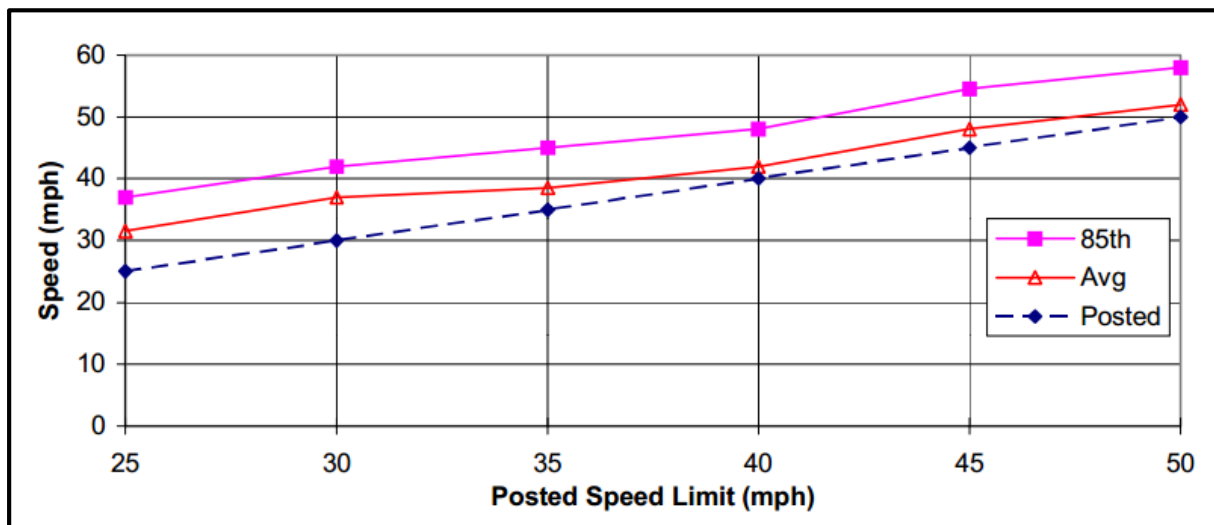
The first step in the study to mitigate traffic congestion is to estimate the amount of traffic on the link at any given point of time. A common method is to place sensors on the road and count the number of times they are actuated by the passing wheels of a vehicle. This approach suffers from four main problems: a) *it is expensive to deploy, as the sensors need to be partially embedded in the tarmac, b) The sensors on the road are prone to theft, c) sensors need to be placed at multiple entry and exit points on the road, to maintain accurate counts, and d) even on a single stretch of road, the sensors need to be placed at regular intervals so as to estimate the density on different segments of the road.* (Vipin Jain et al, 2012) [14]

### 2.3. Interrupted Vs. Uninterrupted Traffic Flow States

#### 2.3.1. Uninterrupted Traffic Flow States

Uninterrupted traffic flow states exist in uninterrupted flow system elements, such as freeways; have no fixed causes of delay or interruption external to the traffic stream. (Praveen Edara and Dan Smith, 2014) [15]

(NCHRP 3-55 (2) A, 2009) [16] suggests a set of linear equations for estimating free-flow speed in uninterrupted flow system elements based upon data gathered on mean speed, and the posted speed limit. **Figure 2.1** shows the relationship of 85th percentile speed, and mean speed to posted speed limit from data developed by Tignor and Warren. Two regression equations are recommended, one for high speed facilities (speed greater than 50 mph), the other for lower speed facilities.



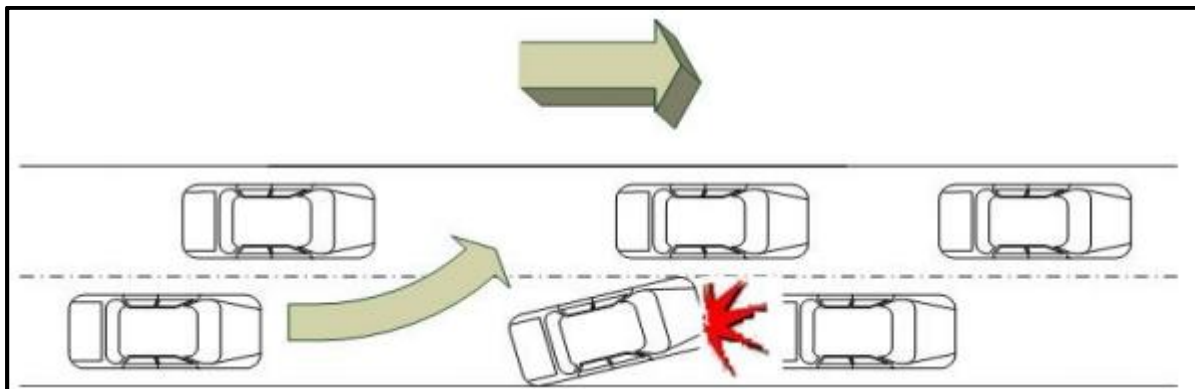
**Figure 2.1:** Speed Limit, 85 Percentile and Mean Speeds in Urban Areas  
(Source: Tignor & Warren)

### 2.3.2. Interrupted Traffic Flow States

Interrupted traffic flow states exist in interrupted flow system elements, such as urban streets; have traffic control devices such as traffic signals and STOP signs that periodically interrupt the traffic stream. (Praveen Edara and Dan Smith, 2014) [15]

Flow interruption leads to congestion and congestion leads to delays, decreasing flow, higher fuel consumption and has negative environmental effects. The cost of total delay in rural and urban areas is estimated by the USDOT to be around \$1 trillion per year. Although congestion during peak hours is expected, congestions at other times are caused by irregular occurrences. This non-recurrent congestion may be due to traffic accidents, disabled vehicles, natural causes such as adverse weather conditions, and spilled loads and hazardous materials. Well over half of nonrecurring traffic delay in urban areas and almost 100% in rural areas are attributed to such incidents.

An “incident” is defined here as any occurrence that affects capacity of the roadway. These incidents might also cause other incidents when response to the initial incident is not fast enough or if the traffic flow is not managed well. (M. Baykal-Gürsoy et al, 2012) [17]



*Figure 2.2: Traffic Flow Interrupted by an Incident*

### 2.3.3. Types of Traffic Flow Interruptions

There are basically two types of flow interruptions: *Recurring and nonrecurring* (irregular occurrences) interruptions. (M. Baykal-Gürsoy et al, 2008) [18] The recurring interruptions are the ones fixed to the infrastructure such as: *intersection control and lateral clearance issues (fixed road side frictions)*. Whereas, the non-recurrent interruptions are due to: *certain driver behaviors, impeding pedestrian movements, non-fixed road side frictions traffic accidents, disabled vehicles, natural causes such as adverse weather conditions, and spilled loads and hazardous materials*.

## **2.4. Traffic Flow Modeling**

### **2.4.1. What is Traffic Flow Modeling?**

Traffic flow modeling is a multi-disciplinary science which adopts the concepts in Traffic Engineering, City Planning, Mathematics and Computer Science in representing traffic flow conditions, congestions and safety issues of interrupted and/or uninterrupted flow states and looks at alternative solutions that prove efficient means of traffic movement. <sup>[7]</sup> (*Scott Miller, 2011*) And they are used in the planning, design and operation of transportation facilities.

### **2.4.2. Types of Traffic Flow Models and Modes**

#### **2.4.2.1. Types of Traffic Flow Models**

Traffic stream models can be performed basically on two model types. They are: *macroscopic* traffic stream models and *microscopic* traffic stream models. In the *macroscopic* traffic stream modeling, the major relationship to be derived is the *fundamental relationships* between Speed, Flow and Density. And representative equations of these relationships are made based on observed field data of uninterrupted flow states. And these will be made by reaching at Single Regime, Multiple Regime or Family of models that can be proven to be evident.

In the *microscopic* traffic stream models, constant, intermediate and random *headways* along with their distribution models using mathematical models are the prime states to capture from available field data. <sup>[19]</sup> (*Adolf D. May, 1990*)

#### **2.4.2.2. Types of Traffic Modes**

The following definitions of traffic modes are based on (*Kashani and Saridis, 1983*). The various traffic situations which may be experienced are partitioned to five categories: sparse traffic, light traffic, heavy traffic, oversaturated traffic, and immobile traffic/incident.

1. **Sparse traffic mode** is declared when there is a very low flow of traffic.
2. **Light traffic mode** is recognized when the arrival rates are low and queues are short.
3. **Heavy traffic mode** is identified by two characteristics: persisting queues and high arrival rates.
4. **Oversaturated traffic mode** is recognized by very long queues, just about to overspill.
5. **Immobile traffic/incident mode** is declared whenever immobility is caused due to an incident or other unpredictable events.

Category 1 and 2 can also be considered as under-saturated traffic. (*J. W. Zwarteveen, 2011*) <sup>[20]</sup>

### 2.4.3. Uninterrupted Traffic Flow Modeling

According to (*Roads and Maritime Services, NSW, 2013*), <sup>[21]</sup> uninterrupted traffic flow modeling shall be any one of the following.

- ✚ **Strategic Modeling** - Transport/Traffic Statistics
- ✚ **Demand Modeling** - Transport Planning
- ✚ **Micro-simulation Modeling** - Microscopic Traffic Flow
- ✚ **SCATSIM Modeling** - Project Suitability and Cost Considerations
- ✚ **Corridor Modeling** - Continuous Flow Stream Modeling
- ✚ **Single intersection Modeling** - Capacity Analysis & Performance Assessment
- ✚ **Computer Modeling** (as a method for the above)
- ✚ **Mathematical Modeling** (as a method for the above)

### 2.4.4. Interrupted Traffic Flow Modeling

In urban settings, since congestions are caused by congestions, interrupted flow condition modeling shall be studied for roadways with the following characteristics on some sections:

- ✚ Occurrence of interrupting **intersections**
- ✚ Occurrence of **accident** or presence of **broken down vehicles** imposing closure of lanes in creating chocked flow conditions
- ✚ **On street parking** and/or loading/unloading stations of taxis and buses
- ✚ **Crossing of pedestrian** at or different location of at grade crossing spots
- ✚ **Irrational driving behavior** with in uninterrupted section affecting the flow stream being operating on adjacent lanes etc.

Thus apparently, congestion problems, queue forming and dissipation at interruptions, saturation flow rate determination at intersections look for interrupted traffic flow modeling. (*Cambridge Systematics, Inc., 2005*) <sup>[22]</sup>

## 2.5. Pedestrian Characteristics and Traffic Flow

As pedestrian characteristics are the human factor in analyzing the traffic and safety problems of transportation facilities, it is the most complex variable to capture. And especially in developing countries like Ethiopia, irrational movement characteristic of pedestrians along or in transverse to the longitudinal flow has been problematic with many regards.

### 2.5.1. Walking Characteristics

Basically, there are two types of parallel walking: on-walkway and off-walkway. Of the two, off walkway movement incur side frictions to vehicular traffic flow in addition to the impedance by perpendicular (crossing) movement.

According to (*Jun Zhang and Armin Seyfried, 2012*), [23] several parameters shall be studied for better representation of existing conditions at heavily congested locations, due to pedestrians. They are:

- ✚ v - velocity (m/s),
- ✚ k - density (1/m<sup>2</sup>),
- ✚ J<sub>s</sub> - specific flow (m/s),
- ✚ J - flow (1/s),
- ✚ A<sub>i</sub> - size of the i<sup>th</sup> Voronoi cell (m<sup>2</sup>),
- ✚ A<sub>m</sub> - size of the measurement area (m<sup>2</sup>),
- ✚ b - width of the corridor (m),
- ✚ C<sub>sb</sub> - capacity of short bottleneck (m/s),
- ✚ C<sub>lb</sub> - capacity of long bottleneck (m/s) and
- ✚ C<sub>cor</sub> - capacity of straight corridor (m/s)

### 2.5.2. Crossing Characteristics

There are numerous studies which deal with the pedestrian road crossing behavior at different locations. The importance of these crossing studies is related to the evaluation of pedestrian facilities, traffic control features and road safety treatments by means of before and after crossing studies on pedestrians' behavior as well as safety. Pedestrians need to cross the road at some location during the course of travel and crosswalks are important for pedestrians to cross the road. The crosswalk locations should provide safe and comfortable movement. (*B Raghuram Kadali et al, 2015*) [24]

In general, there are two types of crossings i.e. at-grade and grade-separated. The later prevents them from crossing randomly at their convenience. Hence, essential for their safety and also reduce vehicular traffic impedance on normal stream flows.

### 2.6. Drivers' Behavior and Traffic Flow

Driving behaviors can be represented by a set of rules describing actions which drivers take in response to driving situation and the situation change to achieve the purpose of the trip. The driving situation is a collection of external factors outside of the vehicle-driver unit, and influence driver's vehicle-maneuvering actions. It includes:

- a. Roadway geometry and conditions such as number of lanes, exit location, and pavement status,
- b. Inter-vehicle driving conditions such as speeds and distances of the surrounding vehicles, and weather conditions such as fog and rain.

Driver's behavior also can be understood in strategic level and tactical level. Strategic behavior is usually determined before the trip starts or far before the

situation looms. Trip route, preferred travel lane and lane changing locations belong to this category. Tactical level driving behavior is determined in real-time. It includes optional lane changing to achieve faster running speed or to avoid a certain danger.

Roadway geometry and conditions are the main factors influencing strategic driving behavior. This behavior can be modeled using choice models such as route choice, lane choice model and mandatory lane changing choice model.

Inter-vehicle driving conditions determine the acceleration of vehicle, which can be represented by car-following models and optional lane changing choice model for passing. These models belong to the tactical level driving behavior.

Weather conditions influence both strategic level and tactical level driving behavior. Fog or heavy rain fall deters trip demand. In driving situation, they affect driver's lane choice in the strategic level, and cause larger gap and lower driving speed for safety's purpose. Therefore, car-following and lane changing behavior in adverse weather conditions are different from the ones without them.

It is better to assume that driving behavior has two components:

- a. Vehicle maneuvering behavior which is directly related to traffic flow, and
- b. Choice situation response. (Hwasoo Yeo, 2008) [25]

## **2.7. City Level Modeling of Traffic Flow**

Urban activities are among the most significant of the Earth's land-uses. And urban systems are still growing in extent and volume throughout the world. In many areas, the pace of urban expansion is actually accelerating, sometimes strikingly so. (P.M. Torrens, 2012) [26] This urban expansion creates huge mobility problem on busy portions of a city in question. The most visible and frequently mentioned transport problem of a city is its traffic congestion, and it is well known that high levels of congestion create significant impact on local and national GDP. (Shanghai Manual, 2010) [27] Moreover, throughout the 1980s and 1990s, Americans spent more and more of their time in cars as commute lengths increased and traffic grew. Personal vehicle travel increased as a share of all travel; carpooling, transit, and walking all declined. (USDOT, 2015) [28] The Texas Transportation Institute estimated that in 2000 the 75 largest US metropolitan areas experienced 3.6 billion vehicle-hours of delay, resulting in 5.7 billion gallons in wasted fuel and \$67.5 billion in lost productivity.

From the above, it is perceivable that to decrease congestion in large cities and improve urban mobility, we have to focus on the better utilization of the existing infrastructure. The development and evaluation of transportation policies for

mobility improvements in cities around the world relies heavily on forecasting models. Given correct inputs, recent sophisticated models can predict much valuable information in disaggregate basis (link flows, travel time in each route etc) on a large transportation network. The problem with this approach is that, when dealing with congested systems, prediction-based evaluation models turn out to be quite fragile. **(Nikolas Geroliminis, 2007) [29]**

## **2.8. Traffic Flow Modeling using Software**

### **2.8.1. The Synchro 9 Software**

The Synchro 9 software is a product of Trafficware Inc. It is standalone application with multi-software package traffic engineering software. The single package software contains five independent applications in it. They are: Synchro 9, TrafficSim, Warrant Analysis, TripGen and 3D Viewer. The Synchro 9 and TrafficSim applications are ideal for Signalized and Un-Signalized Intersections (excluding Roundabouts). **(Trafficware, 2014) [30]** Thus, not ideal for verifying outputs of this research.

### **2.8.2. The VISSIM 9.0 Software**

The VISSIM simulation software is a product of PTV Group, Gauff Consultants who have been in business for a number of decades. It has now reached version 9.0 in that many behaviors and microscopic parameters can be customized. **(PTV Group, 2016) [31]** Thus, taking this advantage, VISSIM 9.0 is ideal software for verification using software in this research.

To tell in short about the assumptions in VISSIM: the traffic flow model in VISSIM is a discrete, stochastic, time step based microscopic model, with driver-vehicle-units as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The model is based on the continued work of Wiedemann.

The basic idea of the Wiedemann model is the assumption that a driver can be in one of four driving modes:

- ✚ **Free driving**, i.e. no influence of preceding vehicles observable.
- ✚ **Approaching**, i.e. the process of adapting the driver's own speed to the lower speed of a preceding vehicle.
- ✚ **Following**, i.e. the driver follows the preceding car without any conscious acceleration or deceleration.
- ✚ **Braking**, i.e. the application of medium to high deceleration rates if the distance falls below the desired safety distance. **(Martin Fellendorf and Peter Vortisch, 2001) [32]**

## **2.9. Assessment of Interrupted Traffic Models**

Even though models of interrupted traffic flow conditions are not made (to date) intensively for sub-Saharan Africa, those studies made in other continents can be looked for assessment. According to **(Kai Plankermann, 2013)** pedestrians and cyclists are the major interrupters of the commuter traffic. And these group were strategically selected on observed scenarios in the country Oman.

Moreover, after identifying the key contributors for the human factors to the observed traffic congestion, vast variables were considered. And upon recommending and making a concluding remark, as far as good design is made, replicable models and parameters can be used. But it was stressed that good to very good condition roads are required. **(Kai Plankermann, 2013)** <sup>[33]</sup>

## CHAPTER THREE: *RESEARCH METHODS, MATERIALS AND PROCEDURE*

### 3.1. Chapter Introduction

In this chapter, the research methods, materials and procedure are presented. Therefore, in doing so, the major study area description is presented in **Section 3.2** while the research procedure was summarized in **Section 3.3**. Moving on, the study design and sample size concepts are analyzed in **Sections 3.4** and **3.5**, respectively. And after discussing the research methods and materials in **Sections 3.6** and **3.7**, respectively, primary data collection details got attention in **Section 3.8**.

### 3.2. Description of the Study Area

In order to conduct this study, the researcher selected one highway corridor for major modeling study and several other intersections and road segments here in Addis Ababa for validation study. The following subsections discuss more.

#### 3.2.1. Location

The major study area is located in Addis Ababa, **Yeka sub-city**. And the traffic flow, pedestrian and drivers' characteristics are representatives of typical urban conditions. **Table 3.1** can be referred for details.

#### 3.2.2. Description of the Highway Corridor

The urban multi-lane highway selected for the research is **Comoros Street (Kebena - British Embassy - Sholla -Diaspora Roundabout roadway link)** is because:

- ✚ **Severe peak hour congestion** at proximity to Diaspora Roundabout
- ✚ **Very extreme pedestrian movement** at Diaspora Roundabout
- ✚ **Different types of intersections** along the corridor (roundabouts, signalized intersections, un-signalized T-Intersections etc).
- ✚ Presence of equally distributed **stable and unstable flow state conditions** on the stretch of the corridor
- ✚ Presence of **segments with a mainline and frontage road** (in which it is analogous to the Addis Ababa City Ring Road)
- ✚ The roadway is very admirable for the **well performing drainage, pavement, pedestrian walkway** etc. facilities (**which makes it ideal condition**) and
- ✚ Observed presence of **incidents, obstructions and lane changing** etc.

### 3.2.3. Driving Conditions

Prior to quantifying vehicle type shares and driver behaviors, the research looked on the following premises to assess and verify. That is, the drivers operating on the study roadway link characteristics were:

- ✚ Small car and mini-bus taxi drivers are *major commuters*
- ✚ Frequent *lane changing behavior* is present
- ✚ *Irrational behavior of drivers* is present at taxi and bus stations at Diaspora roundabout is very high
- ✚ Considerable *frictional interruptions* to other commuter drivers etc.

### 3.2.4. Pedestrian Conditions

Analogous to the declaration in *Section 3.2.3*, pedestrian movement on the study roadway link were characterized as:

- ✚ *Very high pedestrian volume* at taxi terminal and bus station locations
- ✚ They *interrupt the entry flow to Diaspora Roundabout* considerably, augmenting other factors
- ✚ They *interrupt the signal control system (not functioning now)* at Sholla
- ✚ *Crossing movement* yields *greater interruption* to carriageway traffic than movement in the direction of traffic

*Table 3.1:* Description of the Study Area (strengthening the above description)

No.	Description	Major Study Highway
1	Link Name	Kebena - British Embassy - Sholla - Diaspora RA
2	Street Name	Comoros Street
3	Sub City	Yeka
4	Road Classification <sup>[34]</sup>	PAS - 3
5	Number of Lanes (both directions)	8
6	Length (Km) <sup>[34]</sup>	3.0
7	Coordinates (UTM: Easting, Northing)	Start (473901, 998290) and End (475435, 998498)
8	Zone	37
9	Direction	NW73 (Road Heading to the West)
10	ROW Width (m) <sup>[34]</sup>	40
11	Visible Congestions on Peak Hours	Segment: Diaspora Roundabout to Sholla Level: Severe
12	Peak Pedestrian Volume	Each Day Representative: Diaspora Roundabout Level: Extremely High
13	Traffic Composition	On qualitative terms, it is dominated by passenger cars
14	Road Geometry inducing effect on Traffic Operation	No
15	Flow Interruptions	Intersections, Pedestrian Movement, Rare Accidents and Taxi Terminals

<sup>[34]</sup> (AACRA, *Revised Addis Ababa Road Network Master Plan*, 2014)

### 3.3. Research Procedure and Progress Share

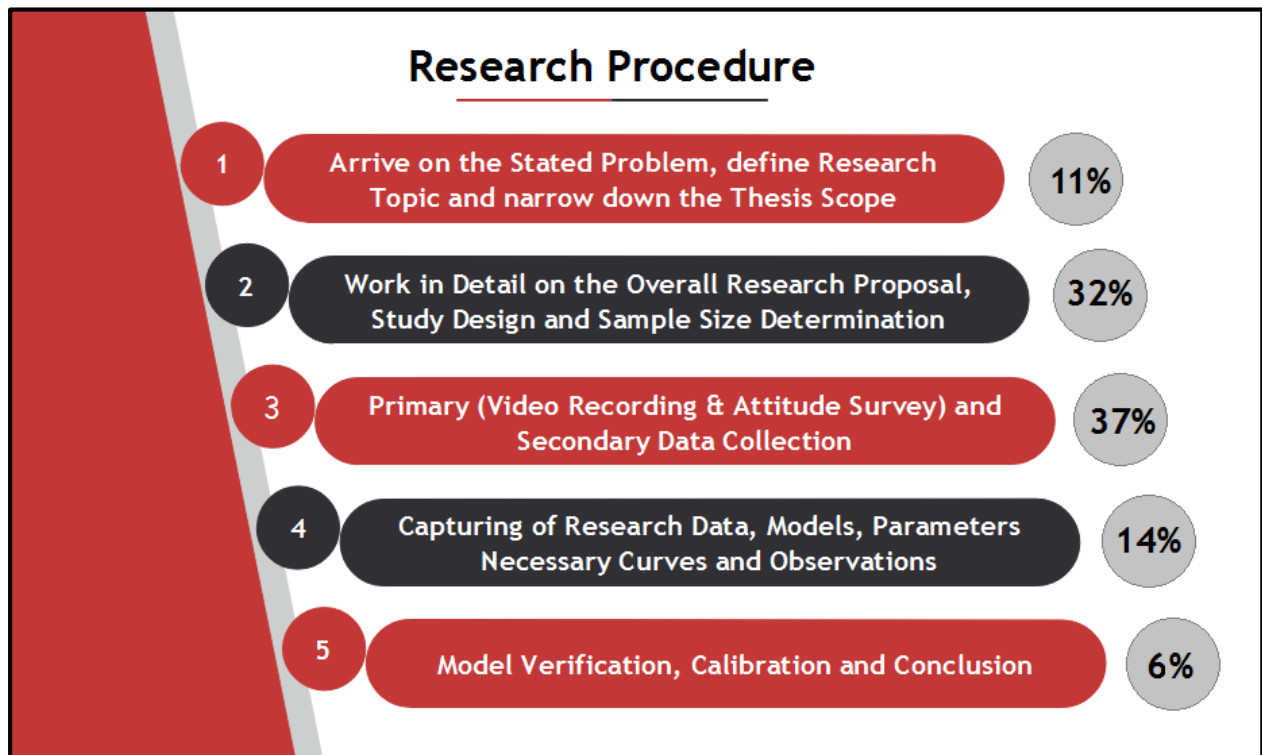


Figure 3.1: Research Procedure and Progress Share

### 3.4. Study Design

In this section, the overall effort of the researcher is shown in how it was tried to look on what data types to focus on. That is: the study design. And as a result, in **Table 3.2**, several researches were reviewed in raw to see what parameters there are that shall be captured. And more narrowed down summary in **Table 3.3**.

Table 3.2: Data Requirement or Study Design (Prior to Narrowing Down)

No.	Modeling of	Focus	The ones to capture?	References
1	Drivers Behavior	Drivers Behavior in a Roundabout	Drivers' Behavior: <b>Conservative + Rational + Urgent + Radical</b> . Basic Behaviors to Model: <b>Throughputs, Arrival Rates and Interactions</b>	(Ruli Wang et al, 2005) [35]
2	Traffic Flow	Counting Guidelines	On <b>uniform</b> geometric characteristics, <b>Flat</b> and <b>horizontal</b> road section, <b>Uninterrupted</b> sections	(Botswana Minis. of Works & Transp., 2004) [10]
3	Traffic Flow	Incident Interruptions	The effects of: <b>Accidents, Disabled Vehicles or Spilled Loads</b> by studying the closure of few lanes or the whole approach of the subject roadway.	(M. Baykal - Gursoy et al, 2003) [36]
4	Traffic Flow	Data to Obtain	Traffic data required count according to: <b>Maneuver, Composition, Vehicle occupancy, Saturation</b> flow rates and <b>Queue</b> length	(J. W. Zwartveen, 2011) [20]

*Development of Models of Interrupted Traffic Flow Conditions of Addis Ababa from a Study of an Urban Multi-Lane Highway*

Item No.	Helps in the Modeling of	Focus of Attention	The ones to capture?	References
6	Traffic Flow	Simulation of Interruptions	Employment of the software VISSIM, data required: <b>Percent</b> composition & <b>Lane width</b> characteristics	(Hemant K. Sharma, 2011) [37]
7	Driver Behavior	Change of Conditions	That result from: <b>Construction Zone and Merging Pattern</b>	(Fereydoun A. et al., 2013) [38]
8	Pedestrian Characteristics	Pedestrian Walking Behavior	Studying the pattern of: <b>Free Speed, Density, Direction</b> (cross, parallel, Jay etc.) & <b>Bottlenecks</b> . Also do capture: Determination and classification into <b>age groups, Trajectory</b> of movement, <b>Density, flow</b> and <b>speed</b> (i.e. Fundamental Diagrams)	(Daamen, W. & Hoogendoorn, SP., 2003) [39]
9	Driver Behavior	Lane Changing	Determination of (as <b>Forced Merging</b> Modeling or other <b>decision</b> model): Decisions to consider, <b>Choice of a target lane</b> and <b>Acceptance of a gap</b> in the target lane	(Kazi Iftekhar Ahmed, 1999) [40]
10	Driver Behavior	Acceleration or Deceleration	In order to do so: Assessment of <b>several speeds</b> with in a uniform road section & Consideration of the additional <b>effect of weaving</b>	(Kazi Iftekhar Ahmed, 1999) [40]
11	Drivers Behavior	Drivers' Aggressiveness	<b>Jam Spacing, Wave Travel Time</b> (in comparison to Reaction Time) and <b>Free Flow Speed</b> . Also studying set of: <b>innate</b> behaviors, <b>Capacity drops</b> and <b>Stop and go</b> traffic phenomena	(Hwasoo Yeo, 2008) [25]
12	Drivers Behavior	Automated or Supported Driving	Study of: <b>Longitudinal Assistance Systems &amp; Lateral Support</b> with respect to: Vehicles and Roadway	(M. M. Minderhood, 1999) [41]
13	Drivers Behavior	Traffic Flow & Drivers' Beh.	Lane changing while: <b>Merging, Diverging</b> or <b>Weaving Model</b>	(Dong Ngoduy, 2006) [42]
14	Pedestrian Characteristics	Conduction of Study	Pedestrian Studies: <b>Manual Count, Video Survey &amp; Attitude Survey</b> . Operation: <b>Space</b> Requirement, <b>Flow-Density</b> Relationships, and <b>LOS</b>	(Tom V. Mathew, 2014) [43]
15	Traffic Flow	Interrupted Facilities	Studies Required: <b>Density</b> and Vehicle <b>Trajectory</b>	(Y.C. Chiu & J A. Villalobos, 08) [44]
16	Pedestrian Characteristics	Movement	Crossing study: <b>Left</b> Intersection, <b>Cross first &amp; walk</b> later, <b>Jay</b> walking, <b>Walk first &amp; cross</b> later, At <b>right</b> intersection, <b>Mid-block</b> cross walk	(Michael J. Markowski, 2008) [45]
17	Driver Behavior	General	<b>Acceleration/Deceleration, Lane changing</b> and <b>Obstruction</b> study	(J. Markowski, Michael 2008) [45]
18	Traffic Flow	General	<b>Speed - Flow</b> Characteristics	Several

**Table 3.3: Data Requirement or Study Design (After Narrowing Down)**

Traffic Flow	Pedestrian Characteristics	Driver Behavior
<ul style="list-style-type: none"> <li>✚ Effects of Accident/Incident (A, Ca) (1, 2, b)</li> <li>✚ Volume According to Maneuver (C, N) (1, a &amp; b)</li> <li>✚ Occupancy (O, N) (1)</li> <li>✚ Saturation Flow Rate (O) (1, b)</li> <li>✚ Composition (O, Ca) (1)</li> <li>✚ Existing Queue Length (O) (1, b)</li> <li>✚ Geometric Characteristics (O, Ca) (1)</li> <li>✚ Density (A) (2)</li> <li>✚ Vehicle Trajectory (O, Ca) (1, b)</li> <li>✚ Vehicular Speed (O, N) (1, b)</li> <li>✚ Access Road Density (C, N) (1, b)</li> <li>✚ Miscellaneous Data (O)</li> </ul>	<ul style="list-style-type: none"> <li>✚ Free Speed (O, N) (1, b)</li> <li>✚ Density (A) (2)</li> <li>✚ Direction:                             <ul style="list-style-type: none"> <li>• Crossing or Parallel (O, N) (1, b)</li> </ul> </li> <li>✚ Bottlenecks (O, Ca) (1, b)</li> <li>✚ Age Groups (O, Ca) (1, b)</li> <li>✚ Trajectory (O, Ca) (1, b)</li> <li>✚ Volume (C, N) (1, b)</li> <li>✚ Attitude Survey (R, N) (3)</li> <li>✚ Space Requirement (A, Ca) (1, b)</li> <li>✚ Crossing:                             <ul style="list-style-type: none"> <li>• Left Intersection, Cross First and Walk Later, Jay Walking, Walk First and Cross Later, At Right Intersection and Mid-Block Crosswalk (O, N) (1, b)</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>✚ At Roundabout:                             <ul style="list-style-type: none"> <li>• Throughput and arrival rates, Interaction in Roundabout and Interaction at entry of roundabout (O, N) (1, a)</li> </ul> </li> <li>✚ Lane Changing:                             <ul style="list-style-type: none"> <li>• Decisions, Target Lanes and Gap Acceptance (O, N) (1, b)</li> </ul> </li> <li>✚ Obstruction Study and Analysis (A, Ca) (2, b)</li> <li>✚ Driver's Aggressiveness and Acceleration/Deceleration:                             <ul style="list-style-type: none"> <li>• Speed Changes, Weaving Effects and Merge/Diverge from Facility (O, N) (1, b)</li> </ul> </li> </ul>

- C - Counts
- N - Statistically Determined Sample Size (Number)
- O - Observation
- R - Response
- A - Analyzed on Desk
- Ca - Case or Category
- (1) - From Video or Recording on Site
- (2) - From Analysis (w/o Requirement of any Data)
- (3) - From Questionnaire
- (a) - At an Intersection
- (b) - In a Road Segment

### 3.5. Data Sample Size Analysis

#### 3.5.1. Traffic Data

##### a. Effects of Accident/Incident

Presence of accidents and/or incidents on an urban multilane highway is one of the interruptions to smooth traffic flow streams. The effects of these conditions range from closure of a single lane in a direction to full closure of the carriageway. Basically, they result from:

- ✚ Accidents
- ✚ Disabled Vehicles
- ✚ Adverse Weather/Road on Maintenance
- ✚ Spilled Loads

To assess such cases, models can be obtained by analyzing the closure of one, two or the whole approach of the subject roadway in study. (*M. B. Gursoy et al, 2003*) [36] Thus, for an eight lane two way urban highway, we will have four cases: Closure of None, One, Two or Three Lanes out of Four Lanes in the Direction (Partial Closure)

##### b. Traffic Volume according to Maneuver

According to (*FDOT, Traffic Analysis Handbook, 2014*) [46], the following must be kept in mind prior to doing so:

- ✚ < 12 months
- ✚ Should be on typical day (Tuesday, Wednesday or Thursday)
- ✚ Weather and incident must not affect flow
- ✚ Calibration data for simulation (if any)

And according to (*MNDOT, 2007*) [47], the typical sample sizes are: for *Average Daily Traffic (ADT) study (24 to 48 hrs)*, *Automatic Traffic Recording (ATR) study (24 hrs/day, 365 days/year)*, *Signal Warrants (6 to 12 hrs, including both peak periods)* and *Vehicle Classification (16 hrs)*. The typical value adopted for this study is the one recommended for Signal Warrants.

##### c. Vehicle Occupancy

It was conducted in complying with the vehicle composition to be discussed in *Section b*, above. According to (*MNDOT, 2007*) [47], the following sample sizes are presented for 95 % confidence interval. The researcher employed study of more than 192 vehicles to detect a difference as small as 0.10.

##### d. Saturation Flow Rate

The saturation flow rate is an ideal value to a flowing traffic stream. It is studied for vehicles with headways less than 4 seconds (a maximum threshold for car following studies). Thus, (*J. W. Zwartveen, 2011*) [20] recommends statistically verified number of headways. Therefore, for an error  $E = |x - \mu| = 15$ , standard deviation  $\sigma$  of 200 and 95% confidence interval, as discussed by (*D. C. Montgomery & G. C. Runger, 2003*) [48] we determined our sample size as:

$$n = \left( \frac{Z\sigma}{\epsilon} \right)^2 = \left( \frac{1.96 * 200}{15} \right)^2 = 683 \text{ headways}$$

#### e. Vehicle Composition

In (MNDOT, 2007) [47] it was written that: “In most cases extreme accuracy is not needed for classification studies. The usual procedure is to collect classification data for one session during the time period of interest e.g. peak hour”

And as per (HCM, 2000) [49], Vehicles for traffic study shall be classified into Heavy Vehicles and Passenger Cars (unlike the usual 7 or 9 vehicle fleet for Pavement Design and Vehicle Operating Cost saving studies).

#### f. Existing Queue Length

According to (MNDOT, 2007) [47] once again, for *segmental* study, **30 seconds long intervals** over the time period in question shall be inspected desirably in **three separate occasions**. And for *intersection* study, the queue on **peak hour** shall get due attention.

#### g. Geometric Characteristics

According to (FDOT, Traffic Analysis Handbook, 2014) [46], the data with regard to this category are: *Functional Classification*, *Lane* (width, number, utilization etc.), *Dimension* (segment length, intersection sizes), *Median* (type, width), *Walkway* (width, utilization) and *Intersection* (type, class, and channelization).

#### h. Traffic Flow Density

According to (MNDOT, 2007) [47], it is similar to occupancy data.

#### i. Vehicle Trajectory

It must be studied analogous to shock wave analysis in complying with the presence of possible incidents/interruptions. Either way, time space diagram is an important tool for demonstrating trajectories. (Y. C. Chiu & J. A. Villalobos, 2008) [44]

#### j. Vehicular Speed

In assessing vehicular speeds in this study, space mean values were assessed rather than time mean values, for many reasons. Thus, (MNDOT, 2007) [47] recommends statistically verified number of values. Therefore, for an error  $E = |x - \mu| = 0.5$ , standard deviation  $\sigma$  of 3 and 95% confidence interval, as discussed by (D. C. Montgomery & G. C. Runger, 2003) [48] we may determine our sample size as:

$$n = \left( \frac{Z\sigma}{\epsilon} \right)^2 = \left( \frac{1.96 * 3}{0.5} \right)^2 = 138 \text{ speeds}$$

#### k. Access Road Density

The number and other assessment data as present on practical conditions.

### I. Miscellaneous Data

According to *(FDOT, Traffic Analysis Handbook, 2014)* [46], the data with regard to this category are: *Pavement* (type and condition), *Street Lights* (presence and condition), *Signs, Signals and Pavement Markings* (types and conditions), and *Parking Characteristics* (presence and type).

**Table 3.4:** Sample Sizes for Vehicular Traffic Data

No.	Description	Sample Size or Case	Remark
1	Effect of incident or accident	Closure of Zero, One, Two or Three Lanes in the Direction	Partial Closure
2	Traffic Volume	6 hrs Traffic Volume Count on a Typical Week Day	On segment On Intersection
3	Vehicle Occupancy	192	Vehicles
4	Saturation Flow Rate	683	Headways
5	Vehicle Composition	Peak hour	vehicles
6	Existing Queue Length	30 seconds long intervals in three separate occasions Peak hour	Segment study and Intersection study, respectively.
7	Geometric Characteristics	Functional Classific'n, Lanes, Dimensions, Median, Walkway and Intersection	Width, Number, Length, Type, Class and Channelization
8	Traffic Flow Density	Ditto as occupancy data	
9	Vehicle Trajectory	Time Space Diagram	Of possible inter'ns
10	Vehicular Speed	138	Of segment Of intersection
11	Access Roads	Density, Contributing Volume Control Type	Practical conditions
12	Miscellaneous Data	Pavement, Street Lights, Traffic Control Devices, Parking Characteristics	Presence, Type & Condition

### 3.5.2. Pedestrian Characteristics Data

#### a. Free Speed

In assessing pedestrian speeds in this study, space mean values were assessed rather than time mean values, for many reasons. Thus, *(Michael R. Bloomberg, 2006)* [50] recommends statistically verified number of values. Therefore, for an error  $E = |x - \mu| = 1$ , standard deviation  $\sigma$  of 3 and 95% confidence interval, as discussed by *(D. C. Montgomery & G. C. Runger, 2003)* [48] we may determine our sample size as:

$$n = \left( \frac{Z\sigma}{\epsilon} \right)^2 = \left( \frac{1.96 * 3}{1} \right)^2 = 35 \text{ speeds}$$

#### b. Density

According to *(W. K. Alhajyaseen, 2010)* [51], pedestrian density study shall be conducted on short segments close to intersections at peak conditions.

**c. Direction: Crossing or Parallel**

Crossing and parallel movement volume splits of pedestrians in the peak hour traffic volume of 15 minutes interval was studied.

**d. Bottlenecks**

Bottlenecks were assessed in two cases. One is with the presence of street vendors and the other one is with poor condition of walkway. And, **(Daamen, W. & Hoogendoorn, SP., 2003) [39]** recommend assessing numerically the reduction in area to the subsequent change in movement pattern and queue.

**e. Age Groups**

Here the pedestrian age group that conflicts the traffic is assessed. According to **(Daamen, W. & Hoogendoorn, SP., 2003) [39]**, three classes are adequate within the peak hour of traffic study. That is: **< 20 years of age (juveniles), 20 to 55 years of age (middle aged) and > 55 years of age (seniors)**.

**f. Trajectory and Crossing Patterns**

According to **Michael J. Markowski (2008) [45]** many possible scenarios related to: **Left Intersection, Cross First and Walk Later, Jay Walking, Walk First and Cross Later, At Right Intersection and Mid-Block Crosswalk** shall get due attention.

**g. Volume**

According to **(FHWA, 2005) [52]**, conflicting movement volume of pedestrians in 15 minutes interval shall be studied. **(Tom V. Mathew, 2014) [53]**

**h. Attitude Survey**

As many researchers recommend, the sample size **5 times** the number of questions in the questionnaire. With **twelve questions** in mind, **60 responses** shall be studied.

**i. Space Requirement**

Space requirement basically shall be looked on three facilities: Medians (pedestrian refuge), crosswalks (crossing movement) and walkways (for parallel movement).

*Table 3.5: Sample Sizes for Pedestrian Characteristics Data*

No.	Description	Sample Size or Case	Remark
1	Free Speed	35	Crossing and Walking
2	Density	On Short segments (100m)	Parallel Movement
3	Direction	Split on 15 minutes interval	Crossing vs. walking
4	Bottlenecks	Reduction in Area, Change in mov't pattern & queue	Due to: Street Vendors & Poor Walkway Condition
5	Age groups	< 20, 20 to 55 and > 55	Their respective share
6	Trajectory and crossing	Possible types of general and crossing movements	On Segmen study
7	Volume	In 15 minutes intervals	Crossing & Walking
8	Attitude Survey	30 Sheets (6 questions each)	Questionnaire
9	Space Requirement	Complying to the volume	Available in the area

### 3.5.3. Drivers' Behavior

#### a. At Roundabout

According to (*Ruli Wang et al, 2005*) [35], throughput and arrival rates, interaction in roundabout and interaction at entry of roundabout are basically studied.

#### b. Lane Changing

In order to conduct detailed assessment of: Decisions, Target Lanes and Gap Acceptance in the Lane Changing behavior of Drivers, (*K. I. Ahmed, 1999*) [40] points out that: *position, speed and acceleration* of each vehicle shall be captured. Thus, (*K. I. Ahmed, 1999*) [40] recommends statistically verified number of values. Therefore, for an error  $E = |x - \mu| = 0.42$ , standard deviation  $\sigma$  of 1.02 and 95% confidence interval, as discussed by (*D. C. Montgomery & G. C. Runger, 2003*) [39] we can determine our sample size as:

$$n = \left( \frac{Z\sigma}{\epsilon} \right)^2 = \left( \frac{1.96 * 1.5}{0.42} \right)^2 = 48 \text{ drivers}$$

#### c. Obstruction Study and Analysis

According to (*Dong Ngoduy, 2006*) [42], possible obstruction shall be studied. For our case, street vending locations and taxi terminals was studied.

#### d. Driver's Acceleration/Deceleration & Aggressiveness

According to (*Hwasoo Yeo, 2008*) [25], Speed Changes, Acceleration/Deceleration and Merge/Diverge from Facility got due attention. Like lane changing behavior of drivers study, **48 cases** shall be studied.

*Table 3.6: Sample Sizes for Drivers' Behavior Data*

No.	Description	Sample Size	Remark
1	At Roundabout	Stalled Vehicles	Throughput and arrival rates, Slow Vehicles in RA
2	Lane changing	48 Drivers	Decisions, Target Lanes and Gaps
3	Obstruction Study and Analysis	Peak hour	Street vending locations and Taxi terminals
4	Driver's Acceleration/Deceleration and Aggressiveness	Visible Cases	Speed Changes, Weaving Effects, Deceleration and Merge/Diverge from Facility

## 3.6. Research Methods

### 3.6.1. Literature Review Composition

The literature that has been reviewed for the *methods, procedures, analysis and interpretation* of the study consist of: Research Journals and Publications, Theses and Dissertations, Books and Manuals.

### 3.6.2. Primary Data Collection

By visiting the study area, the researcher made an effort in collecting primary data for model development. **Table 3.2** can be referred for the detail:

*Table 3.7: Primary Data Collection (Quick Research Facts)*

Item No.	Primary Data Type	Location/s	Quantity or Size	Relevance	Cost (ETB)
1	Video Recording of Traffic Flow Data	Recording at Six Locations for more than Six hours for each perspective.	81.5 GB	<ul style="list-style-type: none"> <li>✚ Traffic Study</li> <li>✚ Pedestrian Movement Study</li> <li>✚ Drivers Behavior Study</li> </ul>	6,438.00
2	Pedestrian Attitude Survey	60 interviews at Diaspora Roundabout	12 qns	<ul style="list-style-type: none"> <li>✚ Verifying observation of pedestrian movement</li> </ul>	1,148.00
<b>Grand Summary</b>					<b>7,586.00</b>

### 3.6.3. Secondary Data Collection

The secondary data used for the research are: *Aerial Images, Geometric Measure Values* and some Assumed *Parameter Values in VISSIM Software*

## 3.7. Primary Data Collection Details

### 3.7.1. Traffic Flow Recording using Video Cameras

The major primary data of this research was collected using video cameras on the day **Wednesday, August 31<sup>st</sup>, 2016** in accordance with the clearly defined points in the *Sample Size* and *Data Quality Assurance* sections (that is: *Sections 3.4* and *3.5*). And to cover the overall range of the study area (that is: the road segment from *Diaspora Roundabout to Kebena Roundabout*), the recording was made on *six perspectives* (as shown in *Table 3.8* and *Figures 3.2 to 3.5*) from *four buildings, simultaneously*. Of all the six perspectives, three shoots were taken from Yeka Sub-city Administration Building. The four buildings used are:

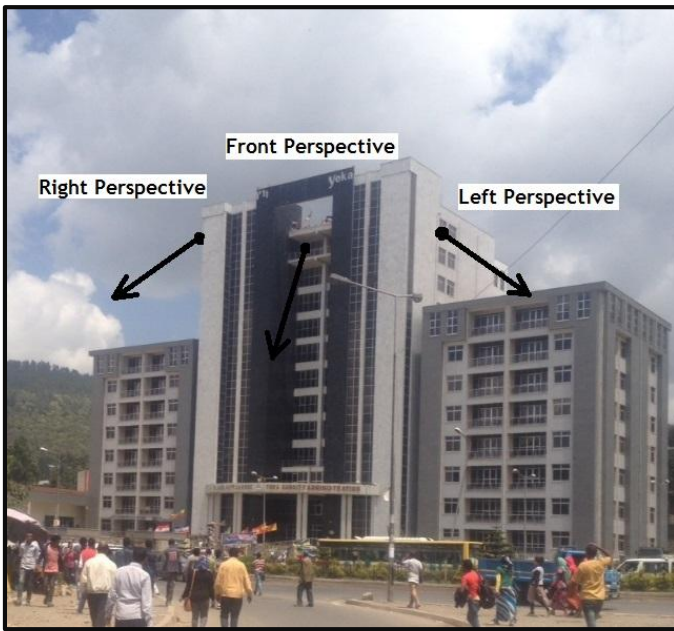
- ✚ Yeka Sub-city Administration Building (*around Diaspora Roundabout*)
- ✚ Sholla First Instance Court Building (*around Sholla*)
- ✚ Menarol Building (*around British Embassy*) and
- ✚ Kebena Area Building (*around Kebena*)

*Table 3.8: Buildings Used for Video Recording*

No.	Building	Floor	Bldg Side (Persp.)	# of Rec. & Crew Size, resp.
1	Yeka Sub-city Admin Bldg ( <i>Fig 3.2</i> )	11 <sup>th</sup> Floor	Left ( <i>Fig 3.7</i> ), Front ( <i>Fig 3.8</i> ) & Right ( <i>Fig 3.6</i> )	3 & 3
2	Yeka First Instance Court Bldg ( <i>Fig 3.3</i> )	4 <sup>th</sup> Floor	Front ( <i>Figure 3.9</i> )	1 & 1
3	Menarol Building ( <i>Fig 3.4</i> )	10 <sup>th</sup> Floor	Right ( <i>Figure 3.10</i> )	1 & 2
4	Kebena Area Bld ( <i>Fig 3.5</i> )	2 <sup>nd</sup> Floor	Front ( <i>Figure 3.11</i> )	1 & 1

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*Figure 3.2: Yeka Sub-city Administration Building (Left)*

*Figure 3.3: Sholla First Instance Court Building (Right)*



*Figure 3.4: Menarol Building (Left)*

*Figure 3.5: Kebena Area Building (Right)*



*Figure 3.6: Video Camera View from Yeka Sub-city Administration Building (from the Building Right Side)*



*Figure 3.7: Video Camera View from Yeka Sub-city Administration Building (from the Building Left Side)*



*Figure 3.8: Video Camera View from Yeka Sub-city Administration Building (from the Building Front Side)*



*Figure 3.9: Video Camera View from Shola First Instance Court Building (from the Building Front Side)*



*Figure 3.10: Video Camera View from **Menarol Building** (from the Building Right Side)*



*Figure 3.11: Video Camera View from **Kebena Area Building** (from the Building Front Side)*

### **3.7.2. Pedestrian Attitude Survey**

The pedestrian attitude survey was conducted from August 8<sup>th</sup> to 16<sup>th</sup>, 2016 on site by interviewing 12 questions to 60 random pedestrians with different ages and professions. The response results are presented in **Chapter Four, Section 4.3**.

## **3.8. Research Materials**

### **3.8.1. Data**

Data for the research contain 26 types. They are as determined and specified in **Section 3.4**. Basically the data types are:

- ✚ Lengths (m)
- ✚ Speeds (Km/hr or m/s)
- ✚ Accelerations/Decelerations ( $m/s^2$ )
- ✚ Gaps (s)
- ✚ Day Time Stamps (HH:MM AM/PM)
- ✚ Video Footage Stamps (MM:SS)
- ✚ Counts (#)
- ✚ Incident or Event (Photo Captures)
- ✚ Several Observations, Notes and Remarks

### **3.8.2. Software**

The software that were used in the conduction of this research are:

- ✚ **Microsoft Word 2013** (Main Text Writing)
- ✚ **Microsoft Excel 2013** (Data Manipulation, Scatter Plots and Curves)
- ✚ **Edraw Max** (for Drawing Flow Charts and Venn Diagrams)
- ✚ **Sigma Plot** (for Scatter Plots and 2D Curves)
- ✚ **Tera Plot** (Plotting of Surfaces or 3D Plots)
- ✚ **Prism** (Bar Charts)
- ✚ **PTV VISSIM 9** (Modeling)

### **3.8.3. Equipment**

The equipment that were used in the conduction of this research are:

- ✚ **Notepads** (Data Recording )
- ✚ **Pens** (Writing)
- ✚ **A4 Papers** (Sketching)
- ✚ **Apple and Samsung Tablets** (Video Camera Shoots)
- ✚ **Tapes** (Fixing Equipment on the Field)
- ✚ **Holding Belts** (Hold the Tablets)
- ✚ **Hard Disk and Flash Disk** (Video File Storage)

## CHAPTER FOUR: *RESEARCH DATA*

### 4.1. Chapter Introduction

This chapter presents the **summary** of acquired research data in three categories: Vehicular Traffic Data, Pedestrian Characteristics and Drivers' Behavior. Thus, **Section 4.2** presents the tables of Vehicular Traffic Data whilst **Sections 4.3** and **4.4** present Pedestrian Characteristics and Drivers' Behavior Data, respectively.

### 4.2. Vehicular Traffic Study

#### 4.2.1. Summary of Traffic Data Tables

*Table 4.1: Summary of Traffic Data*

No.	Data Type	Data Size	Locations	Times of the Day
1	Saturation Flow Rates	1394 Headways	5 Intersections (2 RAs and 3 Un-signalized)	AM, Mid-Day and PM Peak Periods
2	Effect of incident	40 Vehicles	2 Locations (around Diaspora and Kebena RAs)	Random times
3	Traffic Volume (Segments)	15 min. sum. of each of the 8 lanes for 6 hours	On 4 segments	AM, Mid-Day and PM Peak Periods
4	Traffic Volume (Intersections)	15 min. sum. of resp maneuvers (LT, TH & RT or Circ., Ex. or Ent.) for 6 hrs	On 5 intersections	AM, Mid-Day and PM Peak Periods
5	Vehicle Composition	1700 Vehicles	5 Intersections and 17 Approach Legs	Peak Hours
6	Traffic Flow Density	Sample vehicular densities in segments for each 15 minutes for 6 hours	On 4 segments	AM, Mid-Day and PM Peak Periods
7	Vehicular Speeds (Seg.)	Sample vehicular speeds in segments for each 15 min. for each dir'n for 6 hours	On 4 segments	AM, Mid-Day and PM Peak Periods
8	Vehicular Speeds (Inter.)	Sample vehicular speeds in intersections for each 15 minutes for each maneuver for six hours	On 5 intersections	AM, Mid-Day and PM Peak Periods
9	Geometric & Miscellaneous Characteristics (of segments)			
10	Geometric & Miscellaneous Characteristics (of intersections)			
11	Vehicle Trajectory	180 Trajectories	2 Locations on Dry, Raining & Wet Cond.	AM, Mid-Day and PM Peak Periods
12	Queue Lengths	Longest observed conditions	On all facilities	Peak Periods

#### 4.2.2. Sample Traffic Data Tables Reported in Summary

*Table 4.2:* Saturation Flow Rates

Intersection	Time of Study	Number of Sample Vehicles	Average Headway*	Saturation Flow Rates
Diaspora Roundabout	Morning	114	2.02	1785
	Mid-Day	95	1.88	1914
	Afternoon	152	2.11	1704
Sholla Signal not Functioning T Intersection	Morning	113	1.91	1885
	Mid-Day	116	2.04	1765
	Afternoon	114	2.06	1748
Abebe Suk + British Embassy Un-signalized T Intersection	Morning	124	1.97	1825
	Mid-Day	112	2.10	1713
	Afternoon	114	2.26	1593
Kebena Roundabout	Morning	114	1.76	2045
	Mid-Day	114	1.89	1905
	Afternoon	112	1.88	1915

\*The average headway is retrieved from a series of values as shown in Appendix

*Table 4.3:* Effect of Incident or Side Friction on Vehicular Flow

Closure of	Speeds of 10 Sample Vehicles in Km/hr										Average
0 lanes	59.96	59	67.42	64.14	56.99	65.97	57.7	55.95	61.36	62.82	<b>61.13</b>
1 lane	52.08	50.28	48.38	47.13	45.94	44.08	42.95	42.29	40.86	39.31	<b>45.33</b>
2 lanes	14.34	16.28	12.29	25.91	20.23	13.16	21.07	12.92	24.61	14.42	<b>17.52</b>
3 lanes	10.68	14.01	8.7	9.66	14.93	15.95	8.43	11.35	10.29	12.73	<b>11.67</b>

The existing queue length observed on the overall study stretch was captured according to the guide that:

- ✚ For a segment study, 30 seconds long intervals in three separate occasions shall be seen
- ✚ For an intersection study, peak hour queue shall get due attention

Thus having this in mind, the following can be said:

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**Table 4.4:** Observed Queue Length on Peak Hours

No.	Type	Location	Queue Photo Capture
1	Intersection	<b><i>Diaspora</i></b> (Roundabout)	
			
2	Segment	<b><i>Diaspora to Sholla</i></b> (Multi-lane Urban Highway)	

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3 Intersection **Sholla** (Un-Signalized T Intersection)



4 Segment **Sholla to Abebe Suk** (Multi-lane Urban Highway)



5 Intersection **Abebe Suk Area - British Embassy** (Un-Signalized T Intersections)

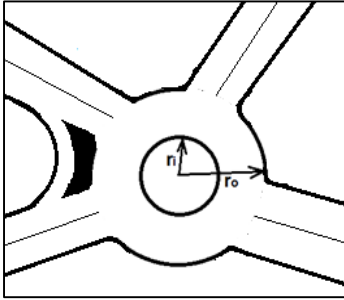
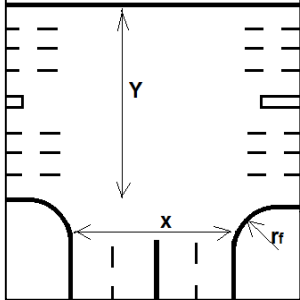
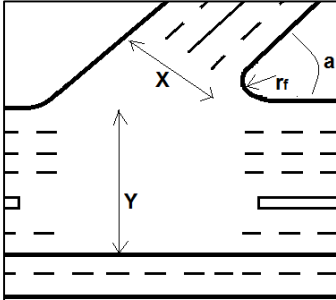
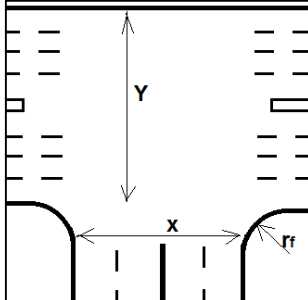
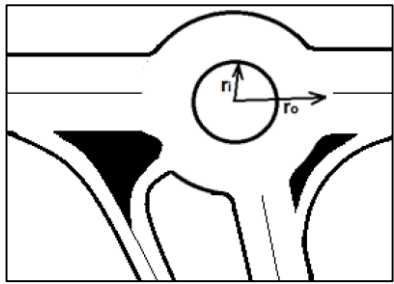


9 Intersection **Kebena** (Roundabout)



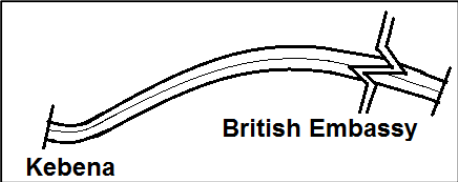
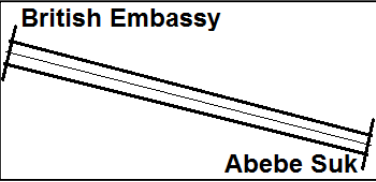
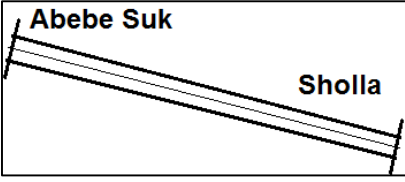
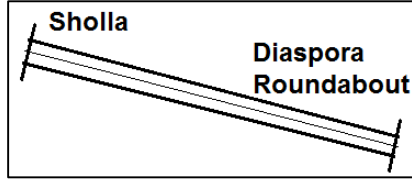
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**Table 4.5:** Intersection Geometric & Miscellaneous Characteristics

No.	Item	Kebena	British Embassy	Abebe Suk	Sholla	Diaspora
1	Type	Roundabout	Un-signalized T-	Un-signalized Y-	Signalized T-	Roundabout Intersection
2	Dimension	$r_i = 16.8 \text{ m}$ & $r_o = 32.9 \text{ m}$	$X = 18.3 \text{ m}$ , $Y = 32.23 \text{ m}$ & $r_f = 6 \text{ m}$	$X = 28.73 \text{ m}$ , $Y = 25.8 \text{ m}$ , $r_f = 5.5 \text{ m}$ & $a = 37^\circ$	$X = 25.3 \text{ m}$ , $Y = 34.8 \text{ m}$ & $r_f = 9 \text{ m}$	$r_i = 30.1 \text{ m}$ & $r_o = 43.5 \text{ m}$
3	Area Type	Urban District other than CBD (UD)	Urban District other than CBD (UD)	Urban District other than CBD (UD)	Commercial Business District (CBD)	Commercial Business District (CBD)
4	Sketch					
5	Class	At Grade	At Grade	At Grade	At Grade	At Grade
6	No of Lanes	4 circ. lanes (rings)	4/dir'nperp'r to Y 2/dir'nperp'r to X	4/dir'nperp'r to Y (2 frontage) 2/dir'nperp'r to X	4/dir'nperp'r to Y 3/dir'nperp'r to X	1 for Bus unloading 3 circulating lanes (rings)
7	Lane Width	$L_{ring} = 4 \text{ m}$	$L_y = 3.5 \text{ m}$ & $L_x = 3.3 \text{ m}$	$L_y = 3.5 \text{ m}$ & $L_x = 3.65 \text{ m}$	$L_y = 3.5 \text{ m}$ & $L_x = 3.45 \text{ m}$	$L_{bus} = 3 \text{ m}$ & $L_{ring} = 3.5 \text{ m}$
8	Channeliz'n	1 RT channelization No LT channelization	No RT channelization No LT channelization	No RT channelization No LT channelization	No RT channelization No LT channelization	2 RT channelization No RT channelization
9	Pav't Type	Bituminous Surface	Bituminous Surface	Bituminous Surface	Bituminous Surface	Bituminous Surface
10	Pav'tCond'n	Very Good	Very Good	Very Good	Very Good	Very Good
11	Street Light	Present	Present	Present	Present	Present
12	Street Light Condition	Non-functional	Somehow Functional	Somehow Functional	Non-functional	Non-functional

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**Table 4.6:** Road Segment Geometric & Miscellaneous Characteristics

No.	Item	Kebena to British Embassy	British Embassy to Abebe Suk	Abebe Suk to Sholla	Sholla to Diaspora RA
1	Length (Km)	1.104	0.487	0.818	0.691
2	Area Type	Urban District other than CBD	Urban District	Urban District	Commercial Business District
3	Sketch				
4	Access Den. (to& fro)	10&5 respectively (with 22 Veh/hr flow on peak)	7& 3 respectively (21 Veh/hr flow on peak)	6& 4 respectively (25 Veh/hr flow on peak)	5& 4 respectively (38 Veh/hr flow on peak)
6	CW widening	None	Yes (2 on the R& 1 on the L)	Yes (1 on both sides)	None
7	Access Control	As a rule of thumb, STOP.	As a rule of thumb, STOP.	As a rule of thumb, STOP.	As a rule of thumb, STOP.
8	On street parking	<20 % on both sides	20 to 50% on both sides	20 to 50% on both sides	>50 % on both sides
10	Road Marking Presence & Type	longitudinal lane lines, transverse crossing lines and direction marks	longitudinal lane lines, transverse crossing lines and direction marks	longitudinal lane lines, transverse crossing lines and direction marks	longitudinal lane lines, transverse crossing lines and direction marks
11	Road Marking Condition	<b>Good</b> - longitudinal lane lines <b>Fair</b> - transverse crossing <b>Poor</b> - direction markings	<b>Good</b> - longitud'l lane lines <b>Fair</b> - transverse crossing <b>Poor</b> - direction markings	<b>Good</b> - longitud'l lane lines <b>Fair</b> - transverse crossing <b>Poor</b> - direction markings	<b>Good</b> - longitudinal lane lines <b>Fair</b> - transverse crossing <b>Poor</b> - direction markings
12	Lanes	# = 4& W = 3.5 m	# = 4 & W = 3.5 m	# = 4 & W = 3.5 m	# = 4 & W = 3.5 m
14	Walkway	4m & No Off Walkway    Mov't	4m, No Off Wkwy    Mov't	4m & No Off Wkwy    Mov't	4m & No Off Wkwy    Mov't
16	Median	Divided& 1.5 m width	Divided & 1.5m width	Divided & 1.5m width	Divided & 1.5m width
18	Pavement	Very Good Bituminous Surface	Very Good Bituminous Surf.	Very Good Bituminous Surf.	Very Good Bituminous Surf.
20	Street Light	Present& in Good Condition	Present& in Good Cond.	Present& in Good Condition	Present& in Poor Condition
22	Taxi Bay	Not Present	Not Present	Not Present	Not Present
23	Frontage	Present (60 %)	Not Present	Present (100 %)	Present (90 %)

### 4.3. Pedestrian Characteristics Study

#### 4.3.1. Summary of Pedestrian Characteristics Data Tables

*Table 4.7:* Summary of Pedestrian Characteristics Data

No.	Data Type	Category	Data Size	Locations	Times of the Day
1	Speed & Density	Pedestrian Characteristics	Sample speeds and densities for each <b>15 min. for 6 hours</b>	Diaspora Roundabout	AM, Mid-Day and PM Peak Periods
2	Volume and Movement Split	Pedestrian Characteristics	Sample volumes and splits for each <b>15 minutes for six hours</b>	Diaspora Roundabout	AM, Mid-Day and PM Peak Periods
3	Movement Bottlenecks	Pedestrian Characteristics	<b>All types</b> of bottlenecks	Diaspora Roundabout	Peak Hour
4	Age Group	Pedestrian Characteristics	<b>50 Pedestrians</b> per 15 minutes for Six hours	Diaspora Roundabout	AM, Mid-Day and PM Peak Periods
5	Trajectory and Crossing	Pedestrian Characteristics	Volumes of respective trajectories in <b>an hr for 6 hrs</b>	Diaspora Roundabout	AM, Mid-Day and PM Peak Periods
6	Attitude Survey	Pedestrian Characteristics	<b>60 Sheets (12 Questions)</b>	Diaspora Roundabout	N/A
7	Movement Spaces	Pedestrian Characteristics	<b>Refuges, Crosswalks and Walkways</b>	Diaspora Roundabout	N/A

#### 4.3.2. Sample Pedestrian Xc's Data Tables Reported in Summary

*Table 4.8:* Pedestrian Movement Bottlenecks

No.	Walkway	Observed Bottlenecks	As a Result	Severity
1	On both sides of Sholla Approach	Street Vendors	<b>Change in Movement Pattern.</b> Thus, off street parallel walking.	Medium
		People standing for multi-reasons	<b>Reduction in Area of Facility.</b> Thus, Slower Mobility	Medium
		Vehicles coming out of parking areas	<b>Pedestrian Queue</b>	Small
2	On both sides of Megenagna and Kotebe Approaches	Street Vendors	<b>Change in Movement Pattern.</b> Thus, considerable mass of pedestrians pursue off street parallel walking	Very High
		People standing for multi-reasons	<b>Reduction in Area of Facility.</b> Thus, Slower Mobility	Very High
		Narrow Walkway	<b>Pedestrian Queue</b>	High
		Water Ponding in Pot Holes	<b>Change in Movement Pattern.</b> Thus, off street parallel walking of pedestrians	High
		Extremely Rough Walkway Condition	<b>Change in Movement Pattern.</b> Thus, off street parallel walking.	High
		Presence of Smelling Spots (as a result of drunk pedestrians urinating at night)	<b>Change in Movement Pattern.</b> Thus, off street parallel walking of pedestrians	High

**Table 4.9:** Pedestrian Trajectory and Crossing: *Reason for Pedestrian Decisions*

Item No.	Movement Type	Movement Direction	Major Reason/s
1	Left Intersection	Perpendicular (Crossing)	Pedestrians those are unloaded from public transport vehicles on the right side of vehicular flow direction (i.e. majorly that come from Arat Kilo and Kotebe)
2	Cross First and Walk Later	Perpendicular (Crossing)	Pedestrians unloaded from a public transport vehicle are more intrigued to make a cross first and walk later decision.
3	Jay Walking	Perpendicular (Crossing)	Pedestrians whose destination is far from the assigned mid-block crosswalk facility.
4	Walk First and Cross Later	Perpendicular (Crossing)	Pedestrians who came walking are more intrigued to make a crossing decision after a walk.
5	At Right Intersection	Perpendicular (Crossing)	Pedestrians who came walking on the left side of vehicular flow direction (i.e. majorly that have walked from Megenagna and Yeka Land Administration areas)
6	Mid-Block Intersection	Perpendicular (Crossing)	As it was observed on site, the Mid-Block Crosswalk pedestrian facility is marked for two major reasons. One, it intends to move away from an intersection in reducing obstruction to exit flow from the Diaspora Roundabout. Second is, it aims to average several pedestrian destinations in the area.
7	Off-Street Walking	Parallel (Walking)	Inconvenient walkway facility (majorly due to <u>street vending, narrow walkway and poor walkway surface</u> )

**Table 4.10:** Pedestrian Trajectory and Crossing: *Counts and Shares*

Period Time	AM Peak Period 8 - 9 AM	Mid-Day Peak Period 9 - 10 AM	Mid-Day Peak Period 12 - 1 PM	PM Peak Period 1 - 2 PM	PM Peak Period 4 - 5 PM	PM Peak Period 5 - 6 PM	Day Average	Percent Share
<b>Generally Parallel and Crossing Movements</b>								
Jay Walking	1255	932	1245	460	1125	2235	1209	42.27%
Mid-Block	1383	1153	473	248	1229	1610	1016	35.53%
Off-Street Walking	295	347	236	35	310	669	315	11.03%
Normal On-street	393	271	315	125	296	518	320	11.18%
<b>Total</b>	<b>3326</b>	<b>2703</b>	<b>2269</b>	<b>868</b>	<b>2960</b>	<b>5032</b>	<b>2860</b>	<b>100.00%</b>
<b>Of all the Crossing and Off Walkway Parallel Movements</b>								
Walk 1 <sup>st</sup> & Cross Ltr	1214	1018	714	281	1101	1775	1017	40.04%
At Right Intersection	345	295	148	65	312	450	269	10.59%
Left Intersection	305	280	177	59	285	483	265	10.43%
Cross 1 <sup>st</sup> & Walk Ltr	1070	839	915	339	966	1806	989	38.94%
<b>Total</b>	<b>2933</b>	<b>2432</b>	<b>1954</b>	<b>743</b>	<b>2664</b>	<b>4514</b>	<b>2540</b>	<b>100.00%</b>

Table 4.11: Pedestrian Trajectory and Crossing: *Movement Trajectories*

Item No.	Movement Type	Percent Share	Movement Trajectories on Study Area
1	Left Intersection	10.43 %	
2	Cross First and Walk Later	10.59 %	
3	Walk First and Cross Later	40.04 %	
4	At Right Intersection	38.94 %	
<b>Total</b>		<b>100 %</b>	

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**Table 4.12: Pedestrian Attitude Survey**

No.	Question	Choice	Overall	Casuals	Commuters	Crossing at Desig. Locations	Crossing at their Conv. Locations
1	Pedestrian Type	a) Commuter Pass by	12	--	12	5	7
		b) Casual Pass by	43	43	--	12	31
		c) Area Commuter	2	--	2	1	1
		d) Area Casual	3	3	--	2	1
		<b>Total</b>	<b>60</b>	<b>46</b>	<b>14</b>	<b>20</b>	<b>40</b>
2	Pedestrian Facility Rating	a) Highly Convenient	0	0	0	0	0
		b) Convenient	7	6	1	2	5
		c) Poor	36	26	10	12	24
		d) Very Poor	17	14	3	6	11
		<b>Total</b>	<b>60</b>	<b>46</b>	<b>14</b>	<b>20</b>	<b>40</b>
3	Reason for Lower Rating	a) Design	27	21	6	8	19
		b) Poor Walkway	27	17	10	10	17
		c) Street Vendors Presence	20	16	4	7	13
		d) High Pedestrian Volume	31	23	8	9	22
		<b>Total</b>	<b>105</b>	<b>77</b>	<b>28</b>	<b>34</b>	<b>71</b>
<b>Venn Diagrams*</b>			<b>Refer Figures - in the Appendix Chapter</b>				
4	Attitude on ease on movement by doing Parallel Walking off walkway	a) Yes	30	25	5	7	0
		b) No, reasons as below	30	21	9	13	5
		i) Accident will occur	16	11	5	8	8
		ii) Congestion will be there	6	4	2	0	6
		iii) No Space to do so	2	2	0	2	0
		iv) No Reason	6	4	2	3	3
<b>Total</b>	<b>60</b>	<b>46</b>	<b>14</b>	<b>20</b>	<b>5</b>		
5	Attention in the presence of defined crossing locations	a) Yes	21	16	5	10	11
		b) No	23	17	6	6	17
		c) I did not notice	16	13	3	4	12
		<b>Total</b>	<b>60</b>	<b>46</b>	<b>14</b>	<b>20</b>	<b>40</b>

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No.	Question	Choice	Overall	Casuals	Commuters	Crossing at Designated Locations	Crossing at their Convenient Locations
6	Crossing Preference	a) At designated crossing location	20	14	6	20	--
		b) At location of your convenience	40	32	8	--	40
		<b>Total</b>	<b>60</b>	<b>46</b>	<b>14</b>	<b>20</b>	<b>40</b>
7	Walking Speed	a) Fast	24	18	6	9	15
		b) Medium	33	25	8	9	24
		c) Slow	3	3	0	2	1
		<b>Total</b>	<b>60</b>	<b>46</b>	<b>14</b>	<b>20</b>	<b>40</b>
8	Types of Vehicles which Threaten their Safety	a) Automobile	11	7	4	3	8
		b) Heavy Truck	22	20	2	9	13
		c) Taxi	28	21	7	11	17
		d) Bus	4	4	0	1	3
		e) No they don't	4	1	3	0	4
		<b>Total</b>	<b>69</b>	<b>53</b>	<b>16</b>	<b>24</b>	<b>45</b>
<b>Venn Diagrams*</b>			<b>Refer Figures - in the Appendix Chapter</b>				
9	Types of Vehicles which they think are aggressive	a) Automobile	3	1	2	2	1
		b) Heavy Truck	20	15	5	6	12
		c) Taxi	39	32	6	14	23
		d) Bus	6	5	2	1	5
		e) None of these are	0	0	0	0	0
		<b>Total</b>	<b>68</b>	<b>53</b>	<b>15</b>	<b>23</b>	<b>41</b>
<b>Venn Diagrams*</b>			<b>Refer Figures - in the Appendix Chapter</b>				
10	Major Contributor for the Peak Hour Congestion in the Area	a) Street Vending	22	20	2	7	15
		b) Greater Demand	25	17	8	8	17
		c) Lower Capacity	25	16	9	10	15
		d) Vehicular Interaction	22	17	5	8	14
		e) Pedestrian Activity	21	15	6	7	14
		<b>Total</b>	<b>115</b>	<b>85</b>	<b>30</b>	<b>40</b>	<b>75</b>

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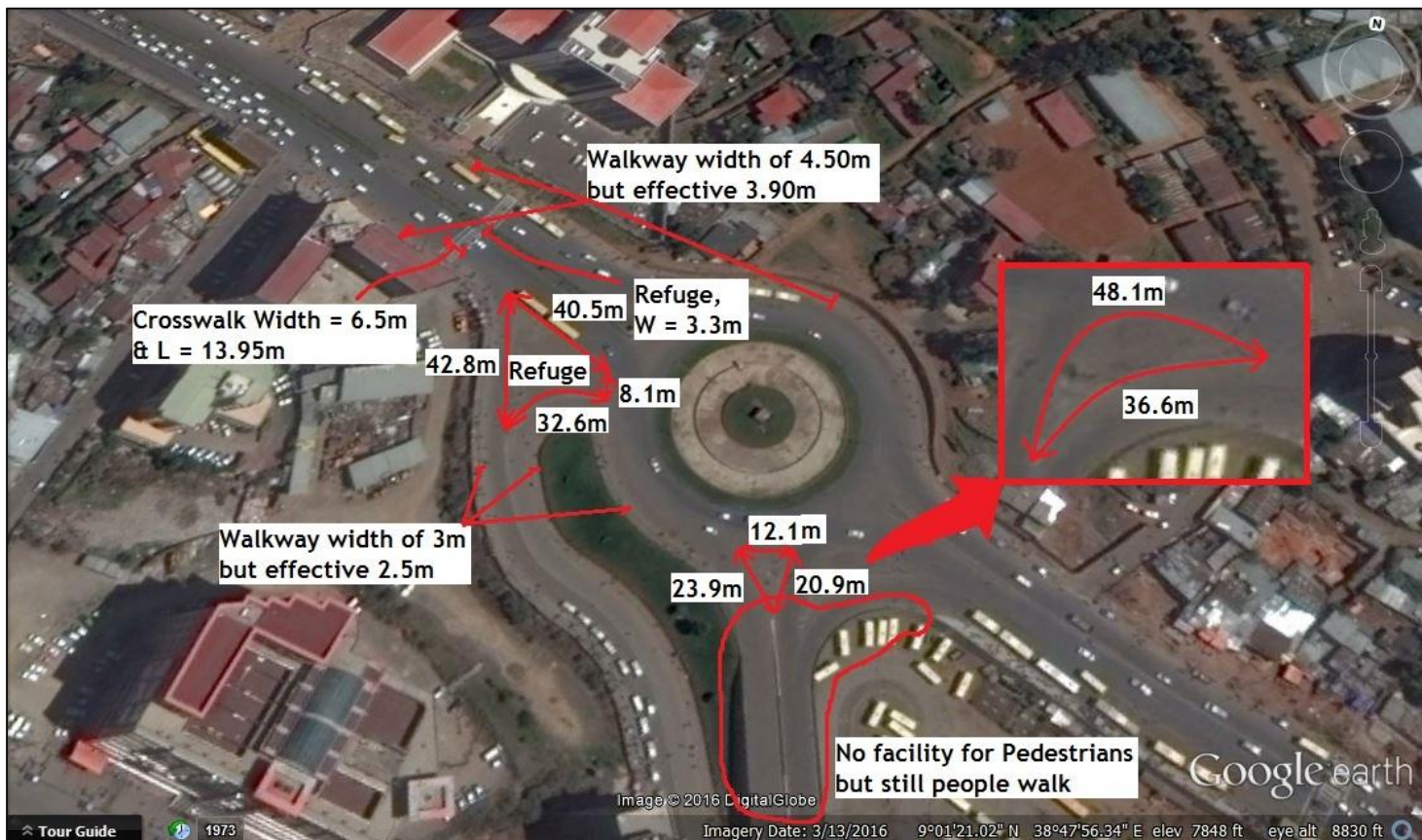
No.	Question	Choice	Overall	Casuals	Commuters	Crossing at Designated Locations	Crossing at their Convenient Locations
11	Effective Measure for the Good of Pedestrians	a) Guard Rail	17	12	5	6	11
		b) Widening	25	21	5	8	17
		c) Ban Street Vending	24	19	5	4	21
		d) Overpass/Underpass Crossing	29	22	7	13	15
		<b>Total</b>	<b>95</b>	<b>74</b>	<b>22</b>	<b>31</b>	<b>64</b>
<b>Venn Diagrams*</b>			<b>Refer Figures - in the Appendix Chapter</b>				
12	Valuable Comments	a) Proper Traffic Study on the Area	2	2	0	2	0
		b) Awareness Creation for Road Users	13	9	4	4	9
		c) Great Volume is present (so there must be due attention)	6	3	3	4	2
		d) Design Change (with/without Pedestrian Overpass Strategies)	12	5	7	5	7
		e) Managing Taxi Terminals & Public Transportation	4	3	1	1	3
		f) Avoid Conflicting Pedestrians	1	1	0	0	1
		g) Widen the Pedestrian Facilities	10	7	3	5	5
		h) Capacity Problems (exit and others)	3	2	1	1	2
		i) Pedestrian 1st Policy (crossing, bridges, light, etc.)	7	4	3	3	4
		j) Better Traffic Control and Management	6	2	4	2	4
		k) Ban Street Vending	12	10	2	4	8
		l) Segregate Pedestrians	3	3	0	1	2
		m) Improve Existing Walkway	9	6	3	2	7
		n) No Comment	11	8	3	4	7
<b>Total Comment Responses</b>			<b>99</b>	<b>65</b>	<b>34</b>	<b>38</b>	<b>61</b>

*\*Venn-diagrams are drawn for multiple responses to a single question to look on interactions*

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**Table 4.13:** Available Pedestrian Facilities

No.	Facility Type	Location	Dimensions	Remark
1	Refuge	In front of Yeka Sub-city Admin. Bldg.	6.50 x 3.30 m	Rectangular Area
2	Refuge	On the island from the Megenagna approach	42.8 m, 32.6 m, (40.5 + 8.1) m	Triangular Area
3	Refuge	On the island from the Bole approach	12.1 m, 20.9 m, 23.9 m	Triangular Area
4	Refuge	Right Turn Channelization to Kotebe	48.1 m, 36.6 m	Oval Area
5	Crosswalk	Sholla Side (in front of Marathon Motors)	W = 6.5 m and L = 13.95 m	The only defined location in the area
6	Walkway	Left and Right of Sholla Approach	W = 4.5 m (3.90 m effective)	Somehow in good condition (except that there is mobility issue due to street vending)
7	Walkway	Left and Right of Megenagna Approach	W = 3 m (2.5 m effective)	Very poor condition (poor walkway and street vending)



**Figure 4.1:** Available Pedestrian Facilities in vicinity of Diaspora Roundabout

#### 4.4. Drivers' Behavior Study

*Table 4.14:* Summary of Driver's Behavior Data

No.	Data Type	Category	Data Size	Locations	Times of the Day
1	In Roundabouts	Drivers' Behavior	Sample interactions and stalling in an hour for six hours	Diaspora Roundabout	AM, Mid-Day and PM Peak Periods
2	Lane Changing	Drivers' Behavior	48 Decisions	Diaspora RA to Sholla	Observed at Random
3	Obstruction Study	Drivers' Behavior	11 Obstructions	Diaspora RA to Sholla	AM, Mid-Day and PM Peak Periods
4	Aggressiveness (Acceleration/Deceleration)	Drivers' Behavior	48 Cases (24 for each cases)	Diaspora Roundabout	AM, Mid-Day and PM Peak Periods

## CHAPTER FIVE – ANALYSIS & DISCUSSION

### 5.1. Chapter Introduction

In this chapter, the research findings are analyzed and discussed analytically, statistically, graphically, in tabular form and qualitatively. In the action to do so, the chapter is divided into four parts: *Traffic Analysis, Pedestrian Characteristics Assessment, Drivers' Behavior Measurements and Relationship Analysis of Several Parameters* in the Study. Thus, *Sections 5.2 to 5.5* are respective to all the findings.

### 5.2. Traffic Analysis

#### 5.2.1. Effect of Incidents

In Addis Ababa, the major types of incidents that partially or fully close travel lanes of multi-lane urban highways are the following:

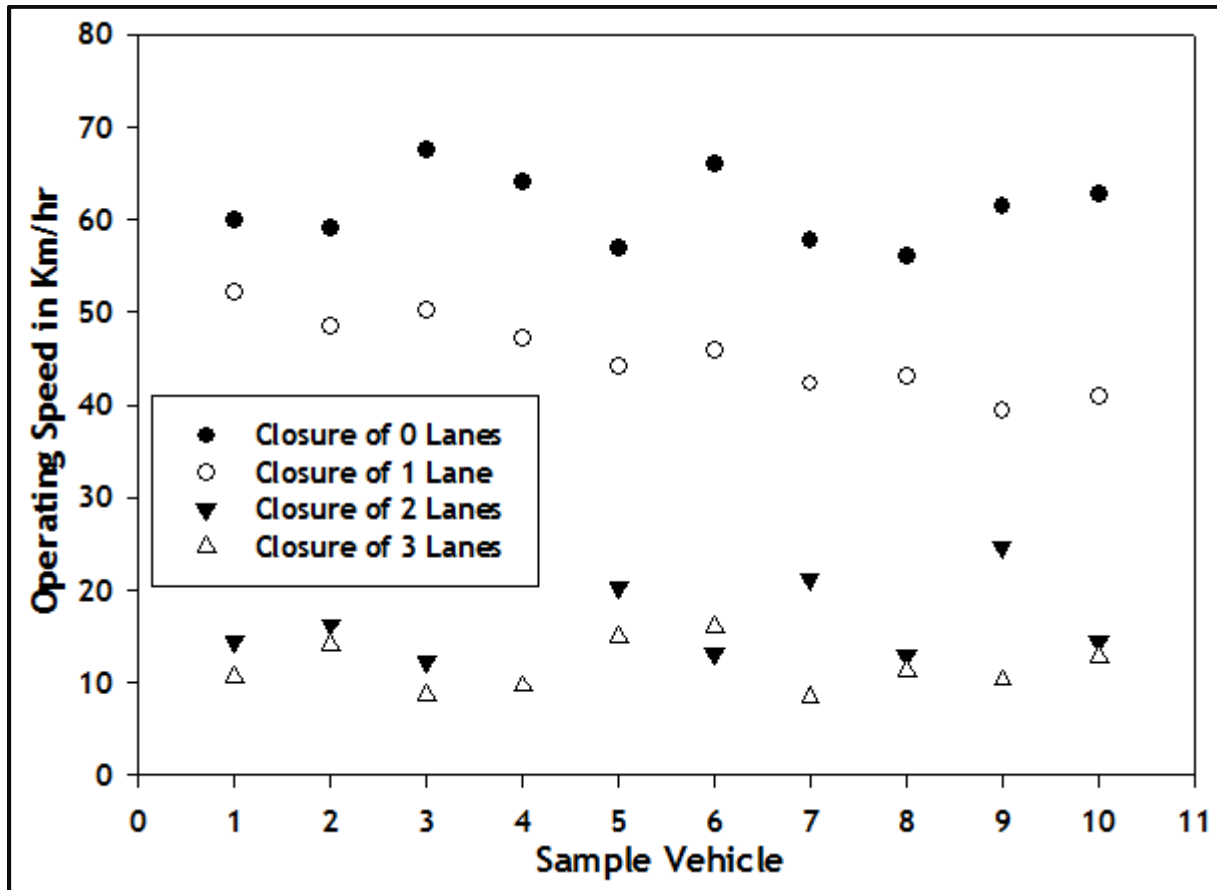
- + Vehicular Accidents,
- + Disabled Vehicles,
- + Loading and unloading of taxis and buses parking and
- + Spilled Loads

And on the study segment studied, disabled vehicles and taxis behavior at terminals were captured as incidents. *Figure 5.1* shows a disabled automobile observed on site (which stayed there for more than 15 minutes).



*Figure 5.1:* Disabled Vehicle Observed close to Diaspora Roundabout

And for such and other cases inspected in the area, the curve in **Figure 5.2** is drawn to show the speed reduction in response to the reduced number of travel lanes. Thus, closure of additional lane in addition to the one hold by on street parking vehicles incurs the greatest reduction. And in order to be able to tell about other scenario, certain statistical measures were obtained, as shown in **Table 5.1**.



*Figure 5.2:* Variations on Speed Reductions on Segments due to Incidents

And according to (**Douglas C. Montgomery and George C. Runger, 2003**) <sup>[54]</sup>, 95 percent confidence intervals can be set (with certain level of confidence) to tell recommended values, for future use. Thus, using the equations written below, it is tried in **Table 5.1**, to show necessary calculations.

$$V_{\text{mean}} = \frac{\sum_{i=1}^n V_i}{n}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^n |V_i - V_{\text{mean}}|}{n - 1}}$$

$$V_{\text{mean}} - Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq V_{\text{mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$$

$$Z_{\alpha/2} = 1.96 \text{ for } 95\% \text{ Confidence Interval}$$

**Table 5.1:** 95 % Confidence Intervals for the Effect of Incidents on Traffic

No.	Statistic Measure	Closure of 0 Lanes	Closure of 1 Lane	Closure of 2 Lanes	Closure of 3 Lanes
1	n	10	10	10	10
2	V <sub>mean</sub>	61.13	45.33	17.52	11.67
3	σ	1.889	1.952	2.198	1.559
4	Z <sub>α/2</sub> * σ / √n	1.234	1.275	1.436	1.019
5	V <sub>mean</sub> - Z <sub>α/2</sub> * σ / √n	59.896	44.055	16.084	10.651
6	V <sub>mean</sub> + Z <sub>α/2</sub> * σ / √n	62.364	46.605	18.956	12.689
7	V <sub>mean</sub> - Z <sub>α/2</sub> * σ / √n ≤ μ ≤ V <sub>mean</sub> + Z <sub>α/2</sub> * σ / √n	59.896 ≤ μ ≤ 62.364	44.055 ≤ μ ≤ 46.605	16.084 ≤ μ ≤ 18.956	10.651 ≤ μ ≤ 12.689

### 5.2.2. Saturation Flow Rate Determination

After surveying **1394 headways** (randomly selected on flow streams at different times of the day and at four intersections of different characteristics), the statistical measures of saturation flow rates are as calculated in **Tables 5.2 to 5.4**. Thus, we can be **95 %** sure that saturation flow rates of Addis Ababa's multi-lane highways range from **1789 to 1820**. And once again according to (**Douglas C. Montgomery and George C. Runger, 2003**) <sup>[54]</sup>, we can use the equations:

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$$h_{\text{mean}} = \frac{\sum_{i=1}^n h_i}{n}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^n |h_i - h_{\text{mean}}|}{n - 1}}$$

$$h_{\text{mean}} - Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq h_{\text{mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$$

$Z_{\alpha/2} = 1.96$  for 95% Confidence Interval

**Table 5.2:** Confidence Intervals for Saturation Flows at Diaspora RA and Shola Intersections

No.	Statistic Measure	Diaspora Roundabout			Shola Intersection		
		AM Peak Period	Mid-Day Peak Period	PM Peak Period	AM Peak Period	Mid-Day Peak Period	PM Peak Period
1	n	114*	95*	152*	113*	116*	114*
2	$h_{\text{mean}}$	2.0165	1.8806	2.1130	1.9133	2.0447	2.0625
3	$q_{\text{sat, mean}}$	1785	1914	1704	1882	1761	1745
4	$\sigma$	0.658	0.571	0.633	0.675	0.590	0.562
5	$Z_{\alpha/2} * \sigma / \sqrt{n}$	0.1082	0.1148	0.1006	0.1245	0.1228	0.1239
6	$h_{\text{mean}} - Z_{\alpha/2} * \sigma / \sqrt{n}$	1.9083	1.7658	2.0124	1.7889	1.9219	1.9386
7	$h_{\text{mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$	2.1247	1.9954	2.2136	2.0378	2.1675	2.1864
8	$h_{\text{mean}} - Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq$	1.9083	1.7658	2.0124	1.7889	1.9219	1.9386
	$h_{\text{mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$
9	$q_{\text{sat, mean}} -$	1694 $\leq$	1804 $\leq$	1626 $\leq$	1767 $\leq$	1661 $\leq$	1647 $\leq$
	$Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq$	$q_{\text{sat}} \leq$	$q_{\text{sat}} \leq$	$q_{\text{sat}} \leq$	$q_{\text{sat}} \leq$	$q_{\text{sat}} \leq$	$q_{\text{sat}} \leq$
	$q_{\text{sat, mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$	1887	2039	1789	2012	1873	1857

\*Refer **Figures 5.2 to 5.5**

**Table 5.3:** Confidence Intervals for Saturation Flows at Abebe Suk, British Embassy and Kebena RA Intersections

No.	Statistic Measure	Abebe Suk - British Embassy			Kebena Roundabout		
		AM Peak Period	Mid-Day Peak Period	PM Peak Period	AM Peak Period	Mid-Day Peak Period	PM Peak Period
1	n	124*	112*	114*	114*	114*	112*
2	$h_{mean}$	1.9727	2.1011	2.2586	1.7572	1.8850	1.8813
3	$q_{sat, mean}$	1825	1713	1594	2049	1910	1914
4	$\sigma$	0.696	0.675	0.654	0.531	0.599	0.573
5	$Z_{\alpha/2} * \sigma / \sqrt{n}$	0.1225	0.1250	0.1201	0.0975	0.1100	0.1061
6	$h_{mean} - Z_{\alpha/2} * \sigma / \sqrt{n}$	1.8502	1.9761	2.1385	1.6597	1.7750	1.7752
7	$h_{mean} + Z_{\alpha/2} * \sigma / \sqrt{n}$	2.0952	2.2261	2.3787	1.8547	1.9950	1.9874
8	$h_{mean} - Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq$	1.8502	1.9761	2.1385	1.6597	1.7750	1.7752
	$h_{mean} + Z_{\alpha/2} * \sigma / \sqrt{n}$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$	$\leq \mu \leq$
9	$q_{sat, mean} -$	1718 $\leq$	1617 $\leq$	1513 $\leq$	1941 $\leq$	1804 $\leq$	1811 $\leq$
	$Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq$	$q_{sat} \leq$	$q_{sat} \leq$	$q_{sat} \leq$	$q_{sat} \leq$	$q_{sat} \leq$	$q_{sat} \leq$
	$q_{sat, mean} + Z_{\alpha/2} * \sigma / \sqrt{n}$	1946	1822	1683	2169	2028	2027

\*Refer **Figures 5.2 to 5.5**

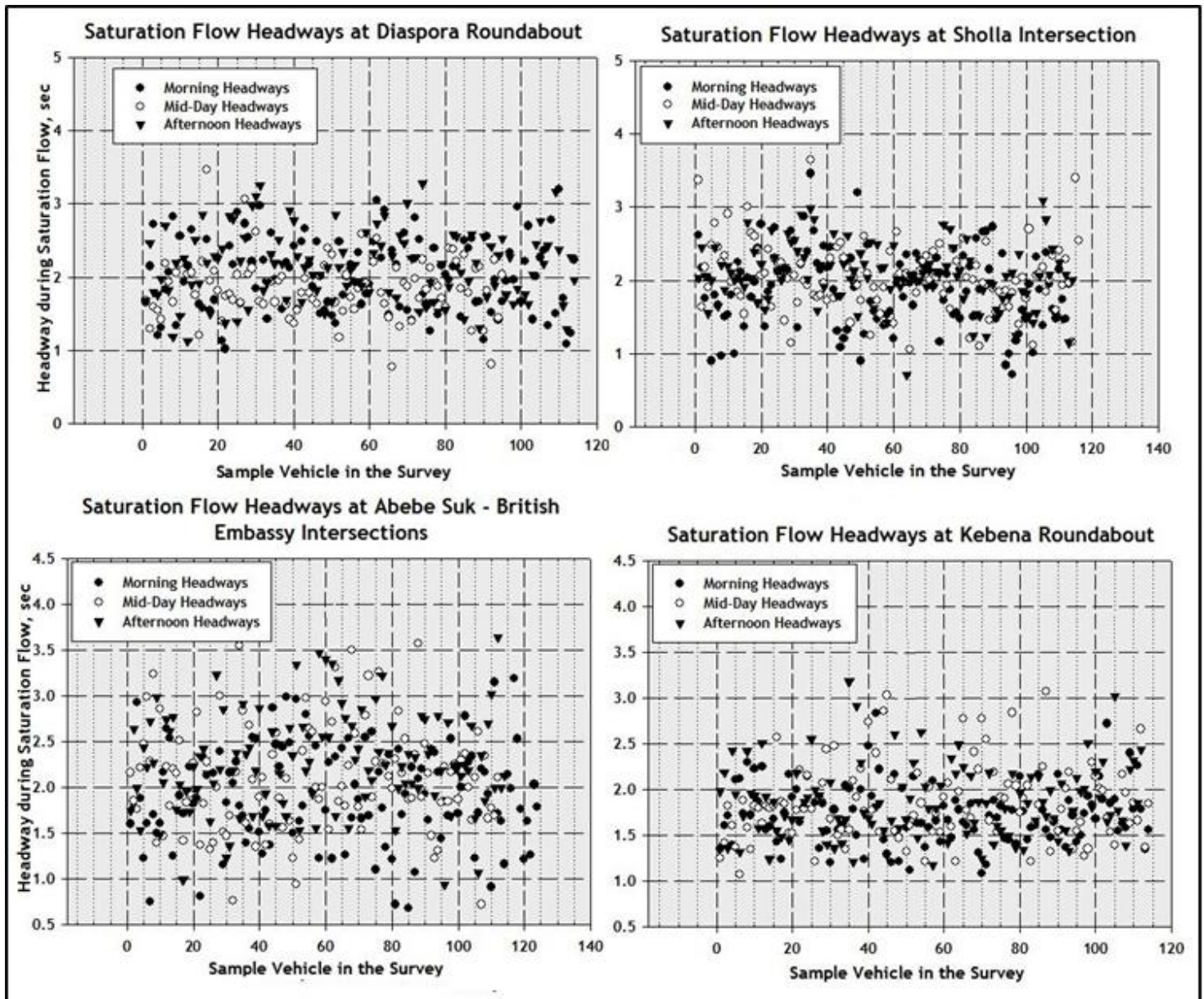
Thus, the above findings can be summarized to:

**Table 5.4:** Overall Assessment of 95% CI for Saturation Flow Rate Estimation

No.	Statistic Measure	Overall
1	n	1394**
2	$h_{mean}$	1.9954
3	$q_{sat, mean}$	1804
4	$\sigma$	0.329
5	$Z_{\alpha/2} * \sigma / \sqrt{n}$	0.0173
6	$h_{mean} - Z_{\alpha/2} * \sigma / \sqrt{n}$	1.9781

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No.	Statistic Measure	Overall
7	$h_{\text{mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$	2.0127
8	$h_{\text{mean}} - Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq h_{\text{mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$	$1.9781 \leq \mu \leq 2.0127$
9	$q_{\text{sat, mean}} - Z_{\alpha/2} * \sigma / \sqrt{n} \leq \mu \leq q_{\text{sat, mean}} + Z_{\alpha/2} * \sigma / \sqrt{n}$	$1789 \leq \mu \leq 1820$



Figures 5.3 to 5.6: Scatter Plot of Saturation Flow Headways at Four Intersections (names are: Diaspora RA Headways, Shola Intersection Headways, Abebe Suk – British Embassy Intersections Headways & Kebena RA Headways)

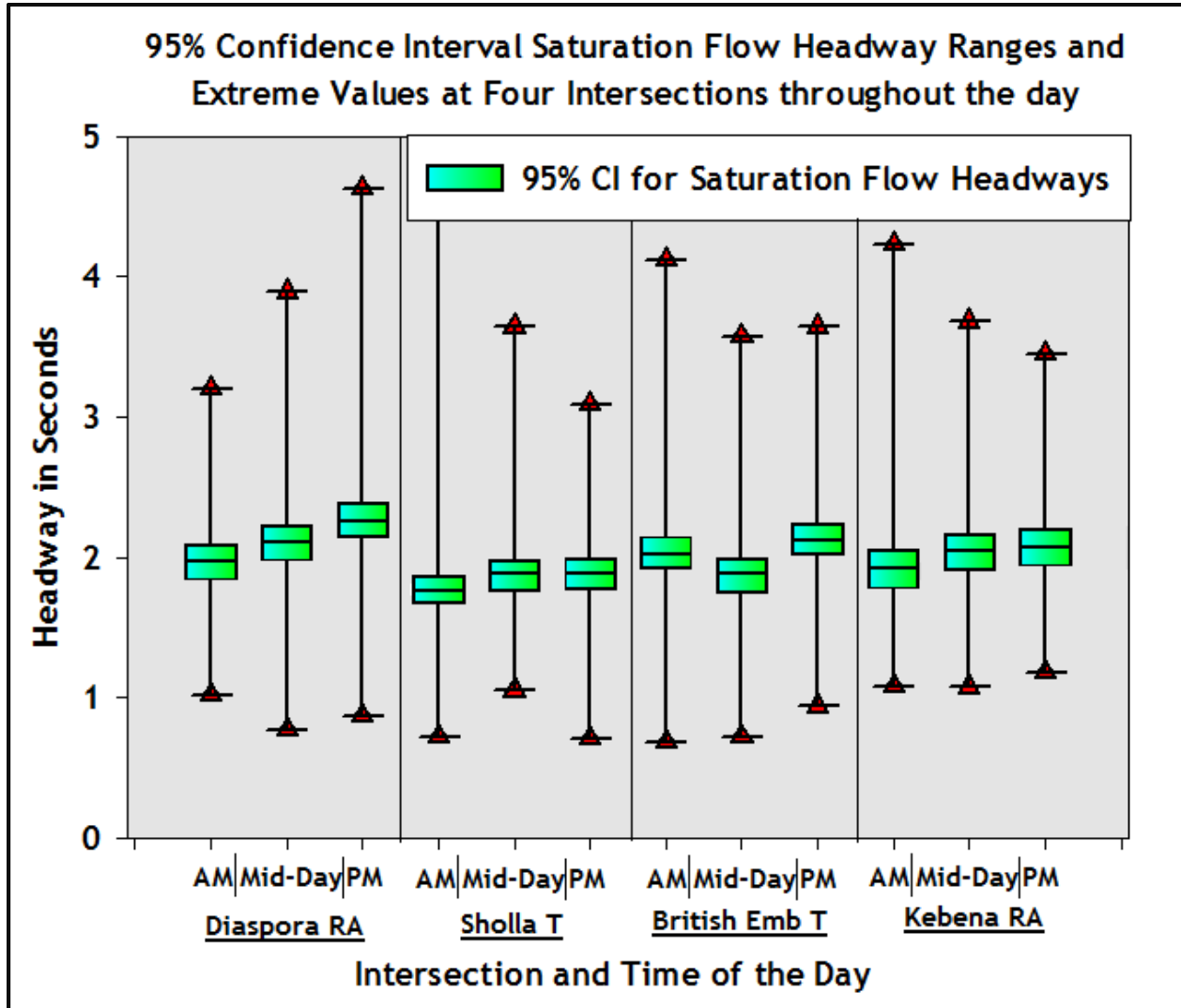


Figure 5.7: 95 % Confidence Intervals and Extreme Headways Captured

### 5.2.3. Vehicle Seats/Occupancy

To assist future studies with respect to occupancy of vehicles, this research investigated the number of seats in the vehicles that are operating on the existing facilities. Thus, the pie-chart displayed in Figure 5.6 shows the summary. As a result, 55 % of the vehicles are *automobiles* and 28 % of the vehicles are *minibus* taxis.

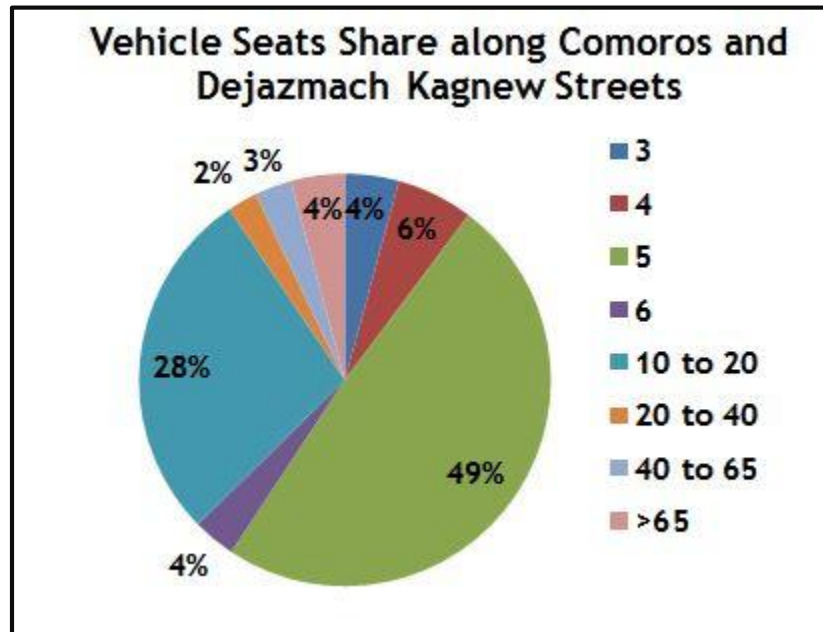


Figure 5.8: Summary Vehicle Seats

#### 5.2.4. Vehicle Composition

The types of vehicles (that is: *three categories* (suiting traffic study) as compared to *nine categories* (for pavement design)) operating on the existing facilities are displayed in the Bar-Chart in Figure 5.7.

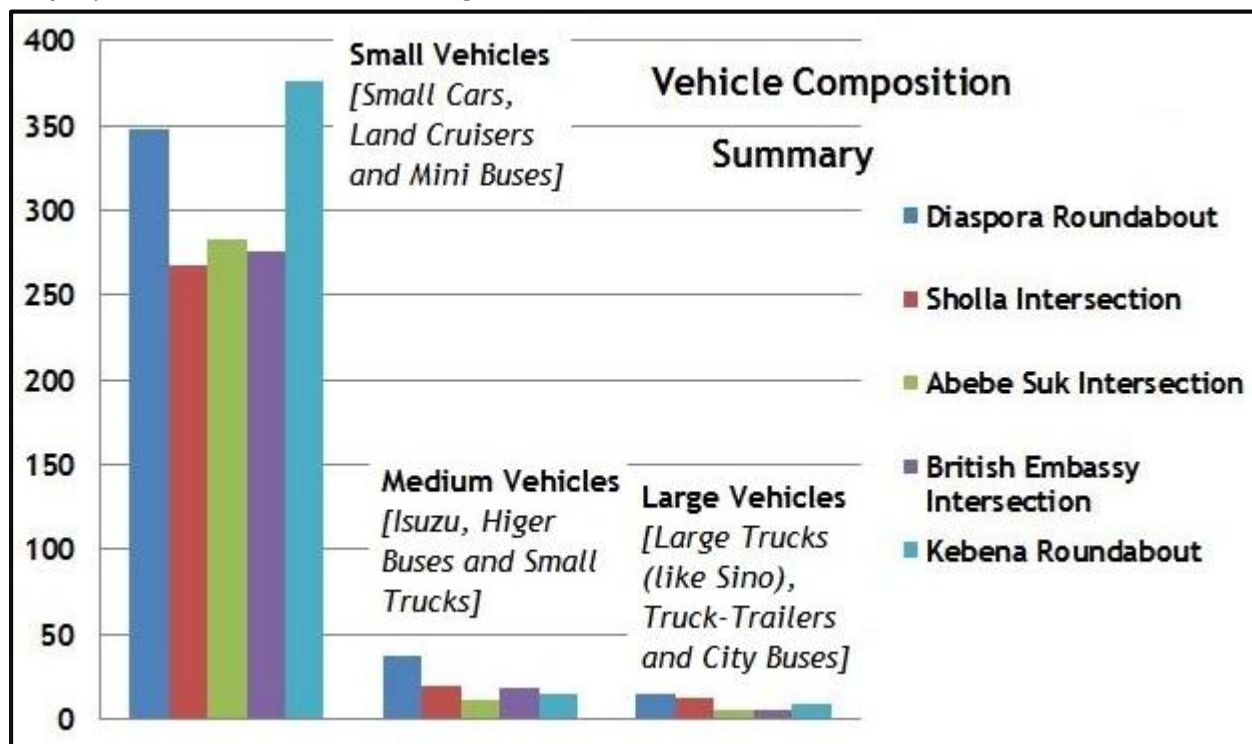
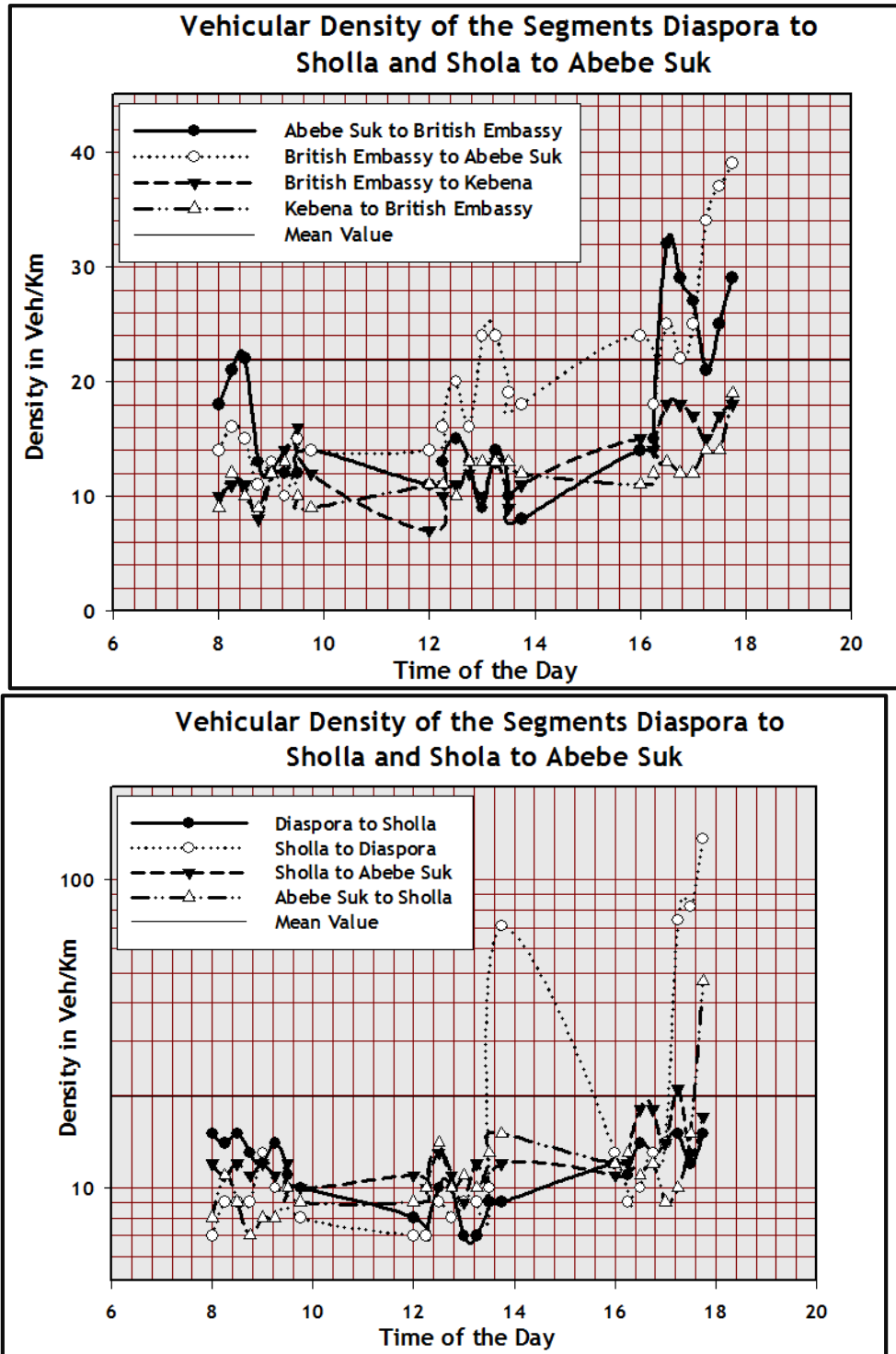


Figure 5.9: Vehicle Composition Summary

### 5.2.5. Vehicular Density

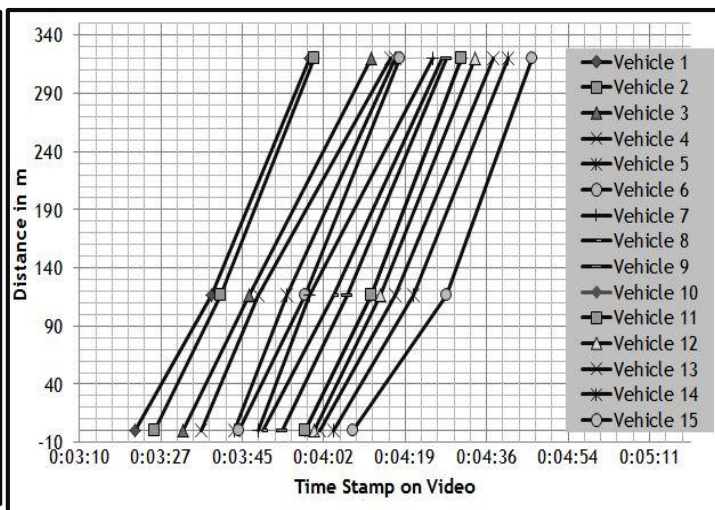
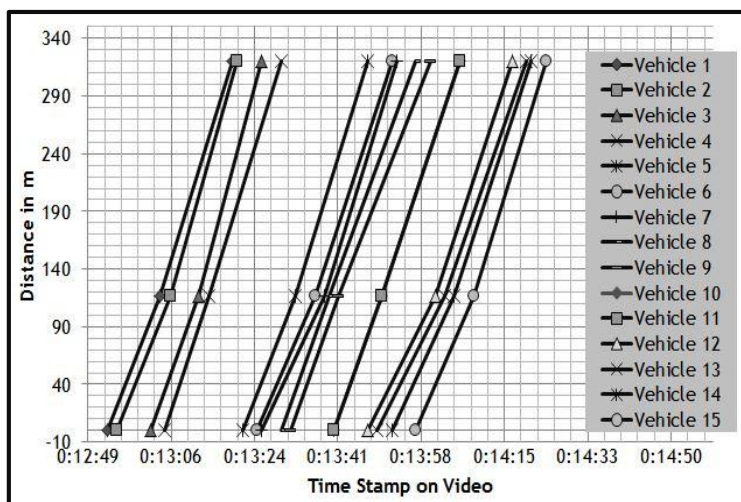
In plotting flow density variations with in a day, different vehicle distributions in travel lanes was averaged to a lane density per km, as shown in **Figures 5.8 & 5.9**.



**Figure 5.10 & 5.11:** Density Variation from Abebe Suk to Kebena (Top) & Diaspora RA to Abebe Suk (Bottom)

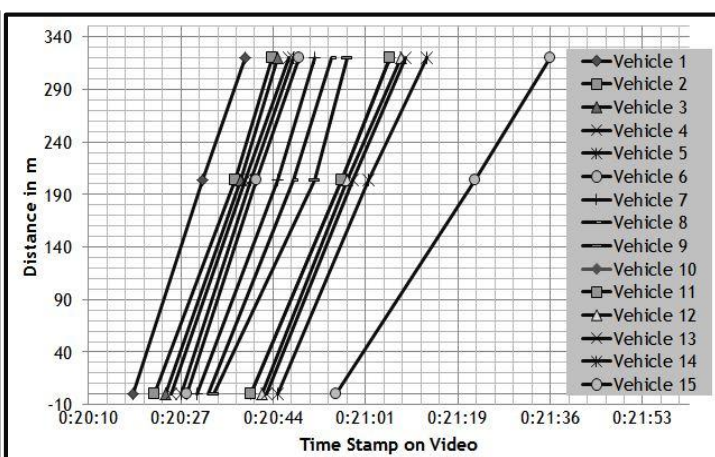
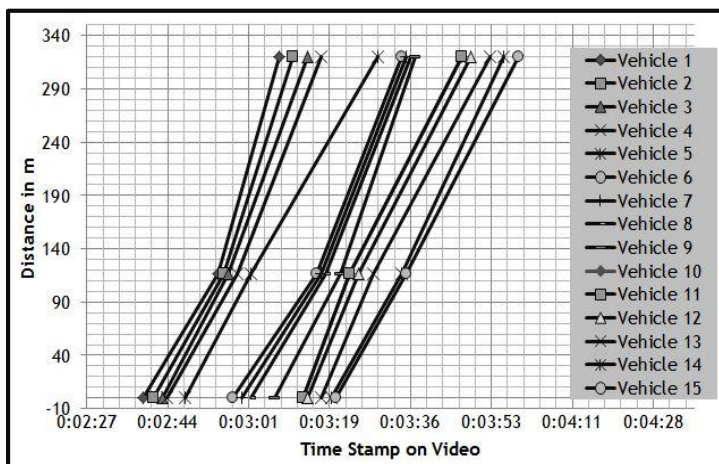
### 5.2.6. Time Space Diagrams

On two different locations along the study highway, time space diagrams were drawn on *three states of weather (dry, wet and raining conditions)* and *three times of the day (AM Period, Mid-day Period and PM Period)*. Refer *Figures 5.10 to 5.21* for the graphs of vehicle trajectories.



*Figure 5.12:* Vehicle Trajectory of Diaspora to Shola on Dry Condition - AM (Left)

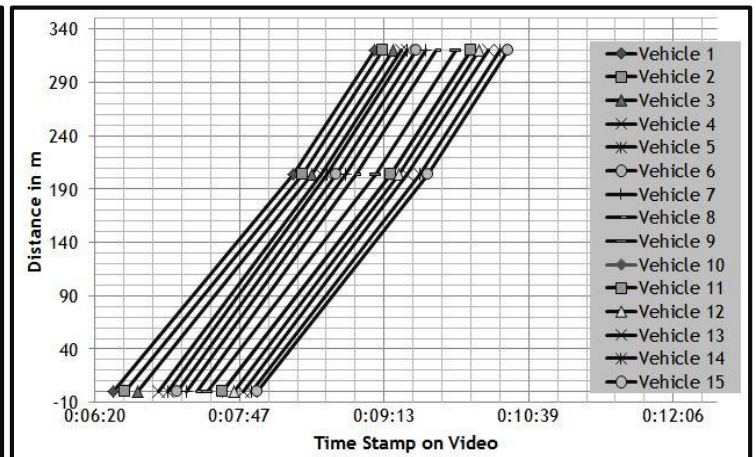
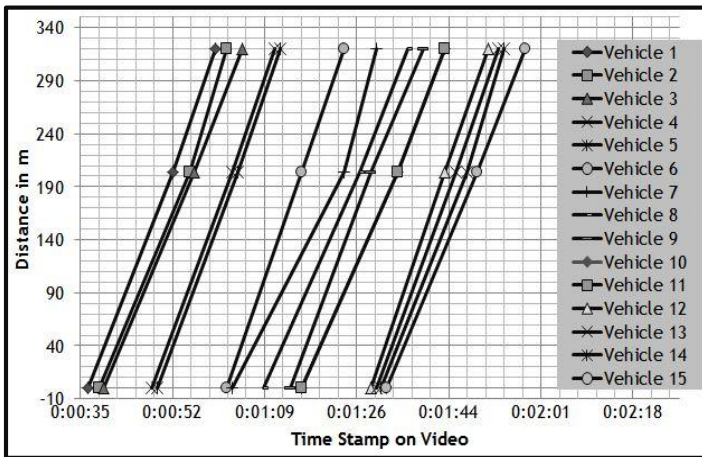
*Figure 5.13:* Vehicle Trajectory of Diaspora to Shola Raining Con. - Mid-Day (Right)



*Figure 5.14:* Vehicle Trajectory of Diaspora to Shola on Wet Condition - PM (Left)

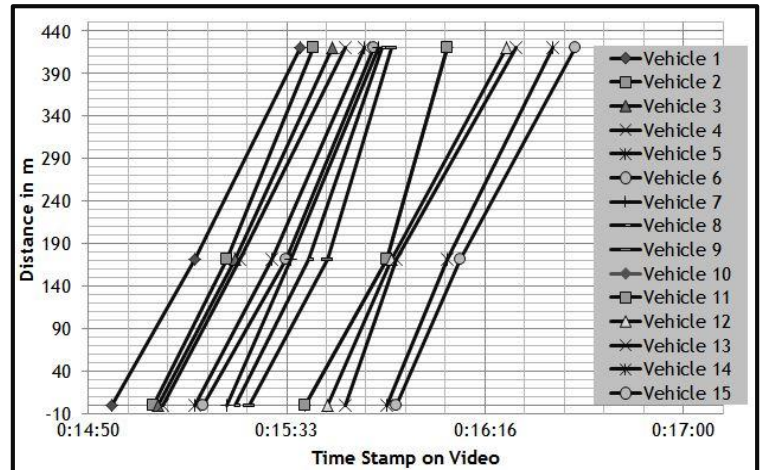
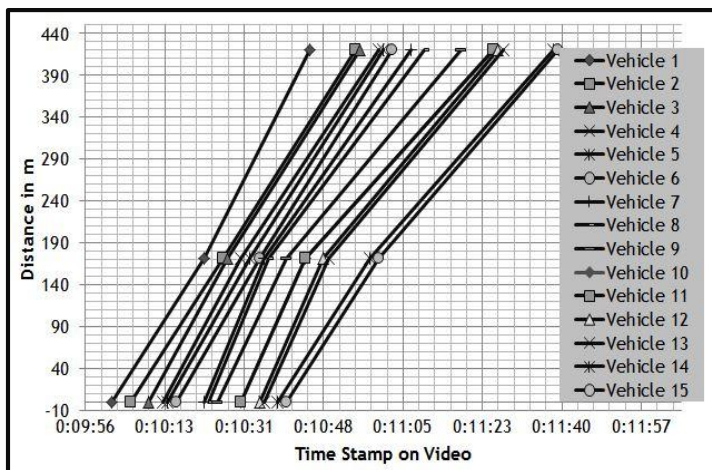
*Figure 5.15:* Vehicle Trajectory of Shola to Diaspora on Dry Condition - AM (Right)

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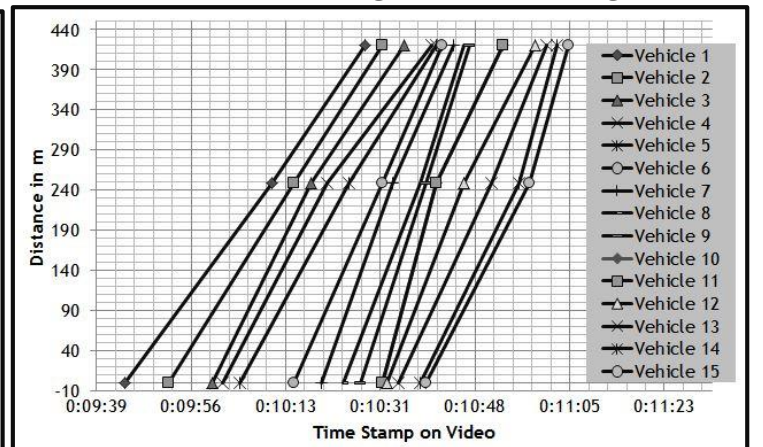
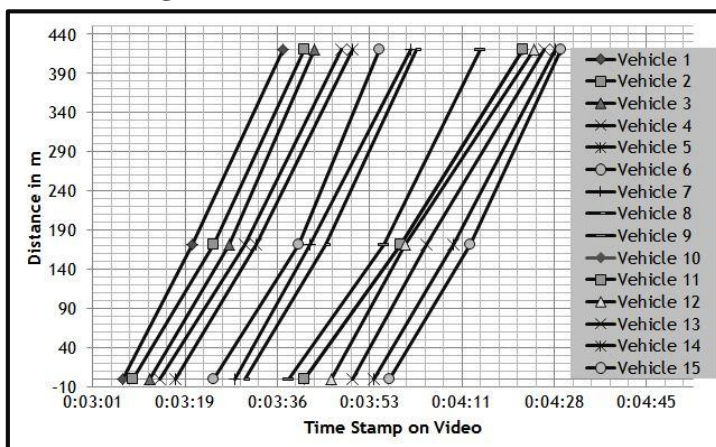
**Figure 5.16:** Vehicle Trajectory of Shola to Diaspora Raining Con. – Mid-day (Left)

**Figure 5.17:** Vehicle Trajectory of Shola to Diaspora on Wet Condition – PM (Right)



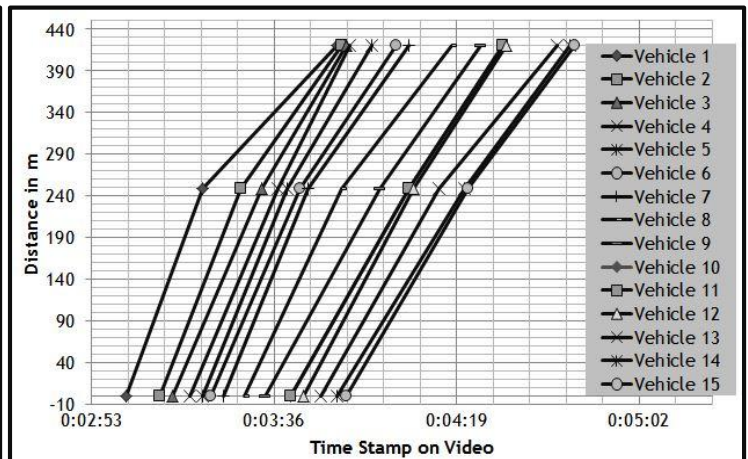
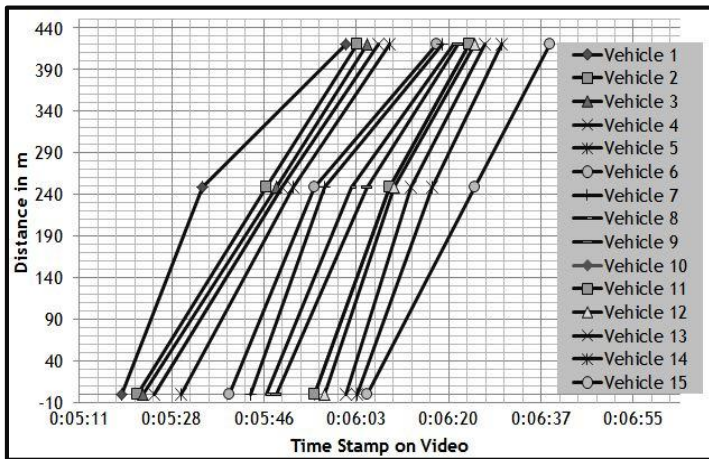
**Figure 5.18:** Vehicle Trajectory of Abebe Suk to Kebena on Dry Cond. - AM (Left)

**Figure 5.19:** Vehicle Trajectory of Abebe Suk to Kebena Raining – Mid-Day (Right)



**Figure 5.20:** Vehicle Trajectory of Abebe Suk to Kebena on Wet Cond. - PM (Left)

**Figure 5.21:** Vehicle Trajectory of Kebena to Abebe Suk on Dry Cond. – AM (Right)

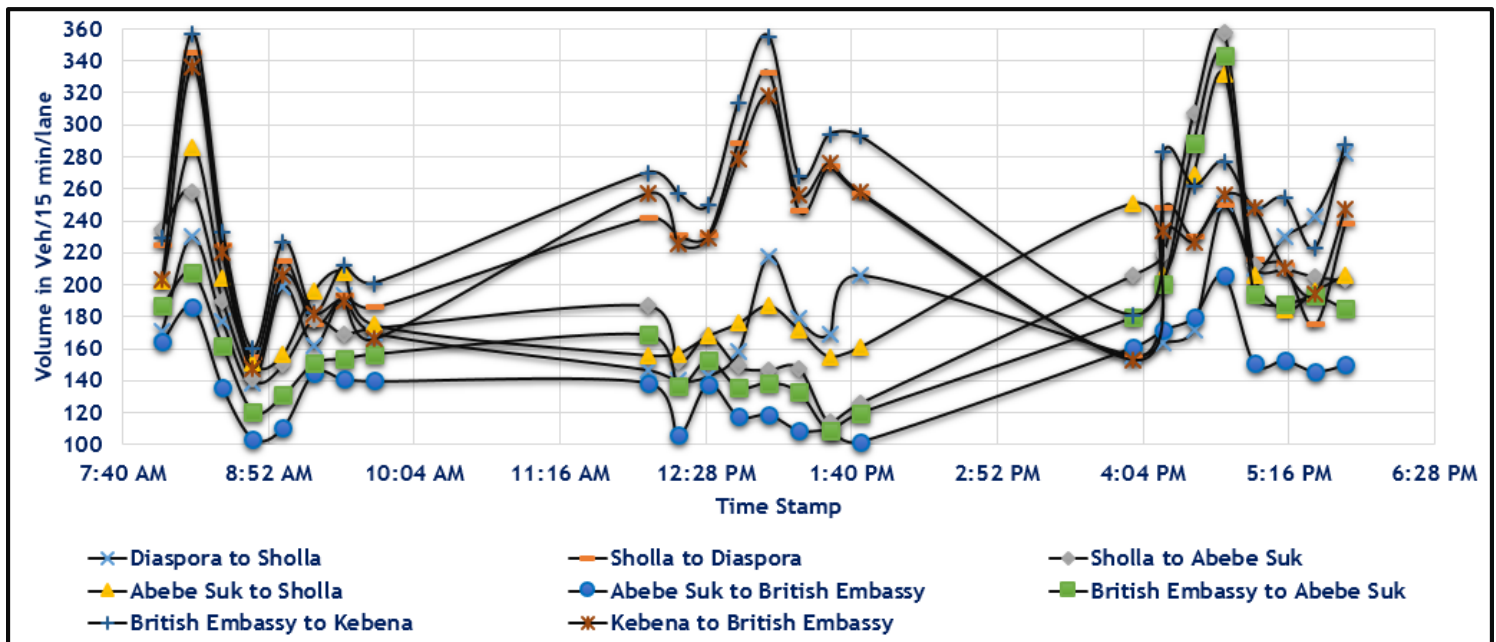


*Figure 5.22:* Vehicle Trajectory of Kebena to Abebe Suk Raining - Mid-Day (Left)

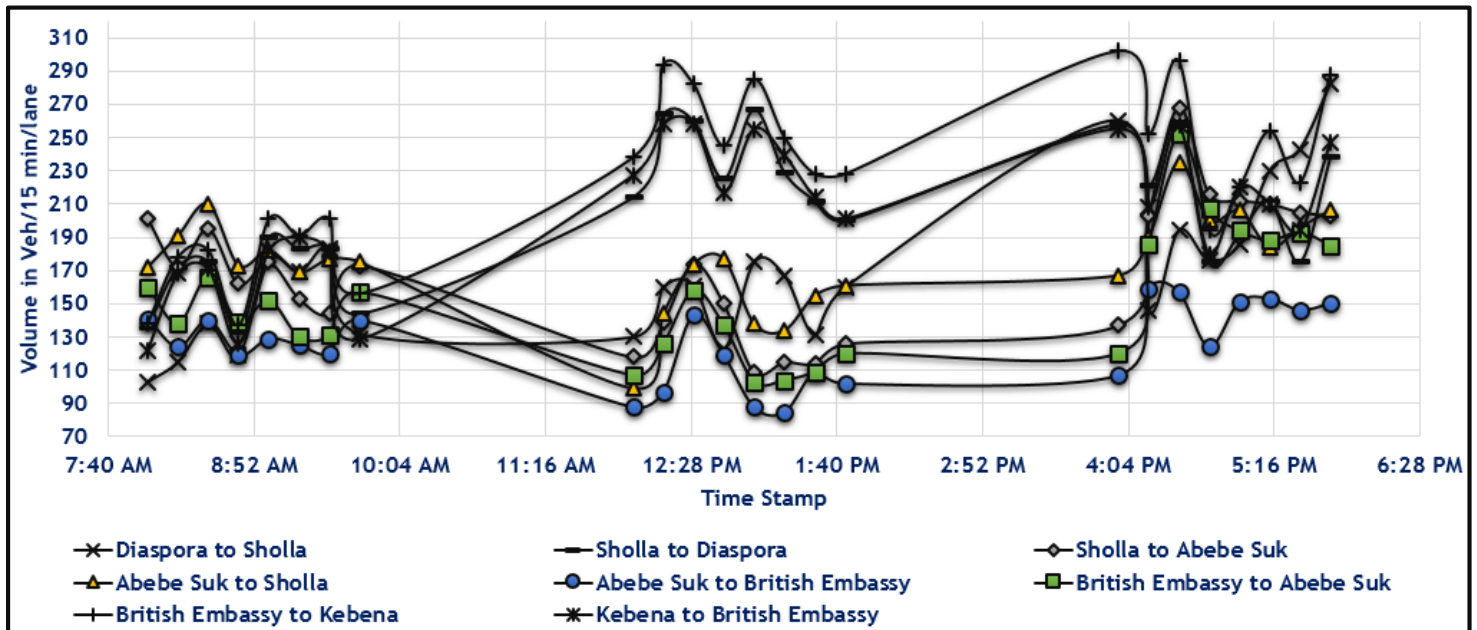
*Figure 5.23:* Vehicle Trajectory of Kebena to Abebe Suk on Wet Cond. - PM (Right)

### 5.2.7. Segment Traffic Flow

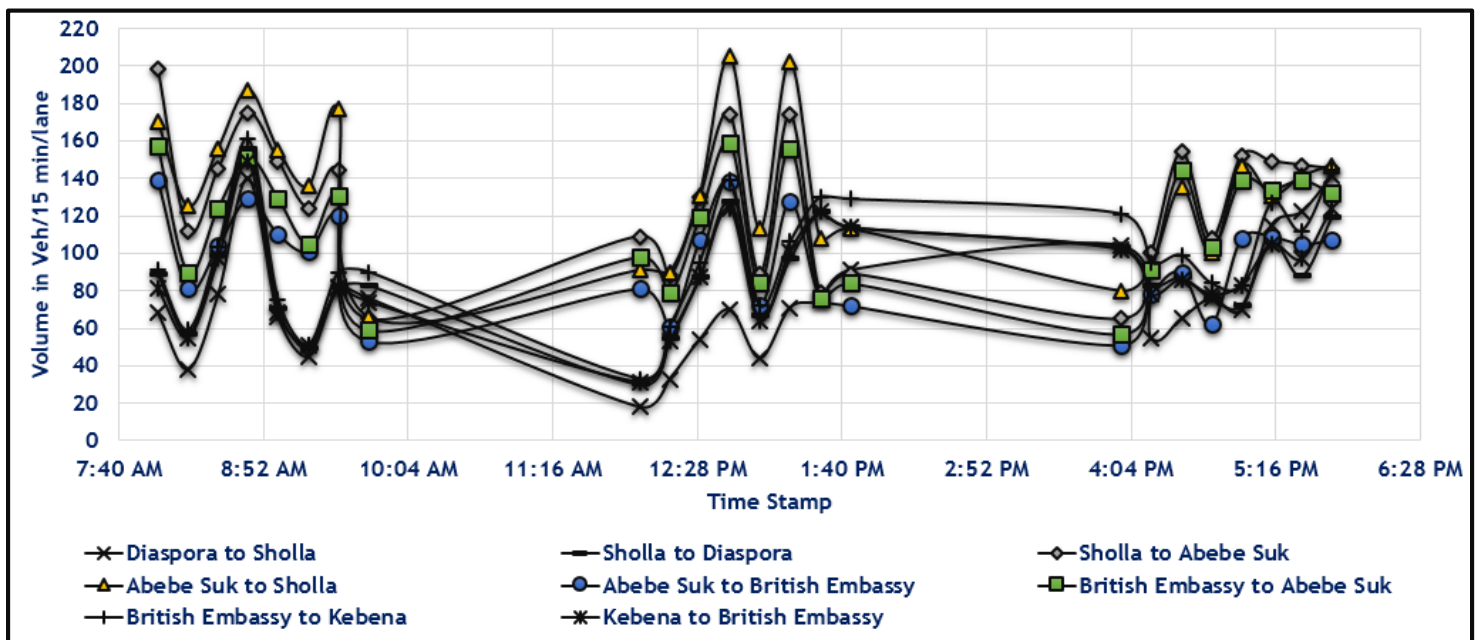
For an eight lane two way urban highway as a study area, the respective flows in each lane was surveyed and is as presented in the *Figures 5.22 to 5.25*. The curves show the variations within the day **31/08/2016** along the four road segments. And referring to (*Highway Capacity Manual, 2000*) [55], the Level of Service (LOS), Demand Flow Rates (Vp) and the Average Travel Speeds (ATS) were obtained using a template developed and attached in the Appendix and are as summarized in *Table 5.4*.



*Figure 5.24:* Flow Variation with in a Day in the inner most lanes (Lane 1)

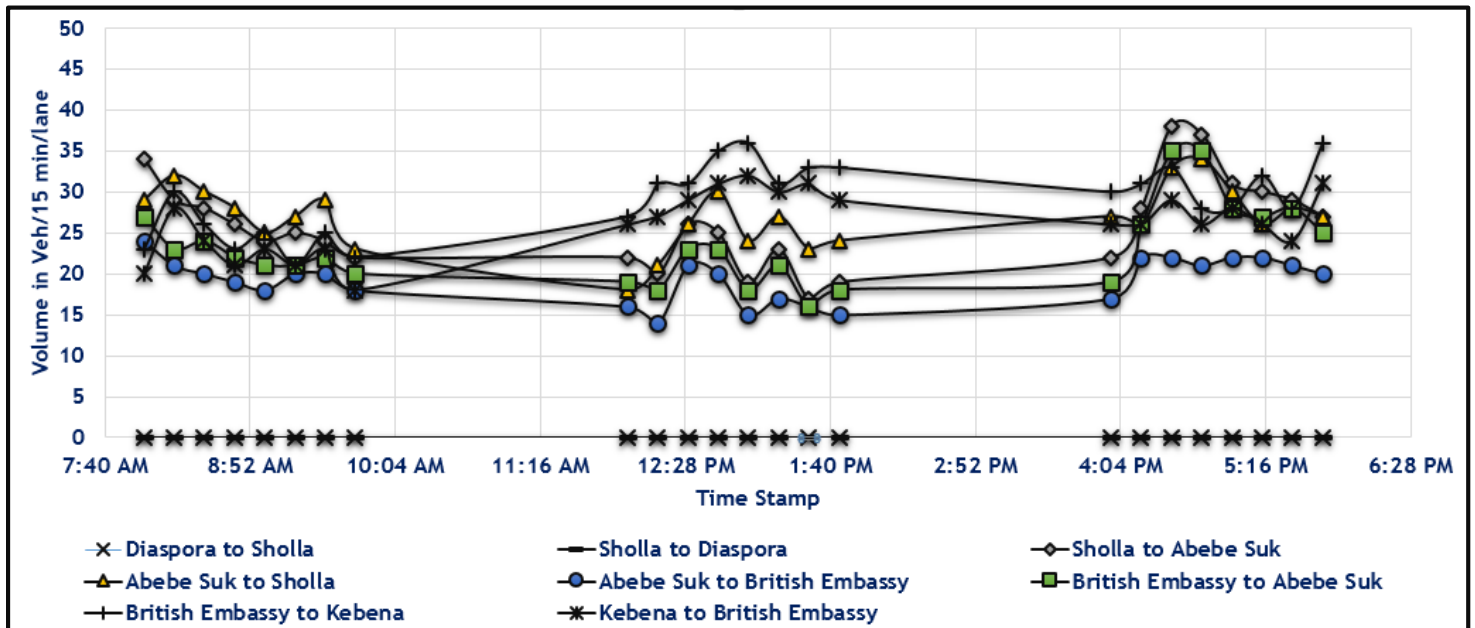


*Figure 5.25:* Flow Variation with in a Day in the 2<sup>nd</sup> lanes referring from the inner most lane (Lane 2)



*Figure 5.26:* Flow Variation with in a Day in the 3<sup>rd</sup> lanes referring from the inner most lane (Lane 3)

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**Figure 5.27:** Flow Variation with in a Day in the outermost lane (Lane 4)

**Table 5.5:** Road Segment Level of Service (LOS), Demand Flow Rates (Vp) and the Average Travel Speeds (ATS) study

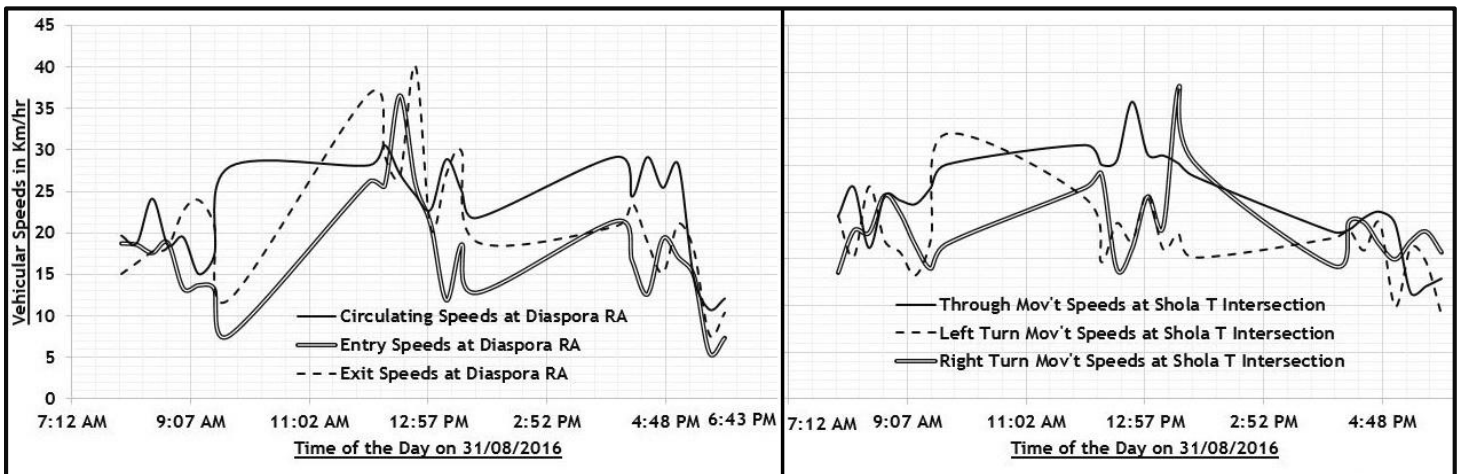
Time	Diaspora to Sholla	Sholla to Diaspora	Sholla to Abebe Suk	Abebe Suk to Sholla	Abebe Suk to British E	British E to Abebe Suk	British E to Kebena	Kebena to British E
<b>Level of Service (LOS)</b>								
8 - 9 AM	B	B	B	B	C	C	C	B
9 - 10 AM	B	B	B	B	B	B	C	B
12 to 1 PM	B	B	C	B	B	C	B	C
1 to 2 PM	B	B	C	B	B	C	B	C
4 to 5 PM	B	B	C	C	C	C	C	C
5 to 6 PM	C	B	B	C	C	C	C	C
<b>Demand Flow Rates (Vd) in Pc/hr/lane</b>								
8 - 9 AM	608	717	767	741	897	831	915	768
9 - 10 AM	700	613	684	652	738	769	810	696
12 to 1 PM	547	625	880	648	714	1015	727	920
1 to 2 PM	698	518	943	550	588	1081	740	991
4 to 5 PM	795	686	836	892	962	1001	928	866
5 to 6 PM	1077	668	797	847	924	1009	882	892
<b>Average Travel Speeds (ATS) in Km/hr</b>								
8 - 9 AM	29	48	43	61	33	40	63	53
9 - 10 AM	34	42	39	53	40	39	40	44
12 to 1 PM	42	48	39	55	37	42	50	56
1 to 2 PM	41	36	35	54	39	34	48	53
4 to 5 PM	34	42	40	47	30	30	39	48
5 to 6 PM	32	14	36	39	24	20	35	41

### 5.2.8. Vehicular Speeds

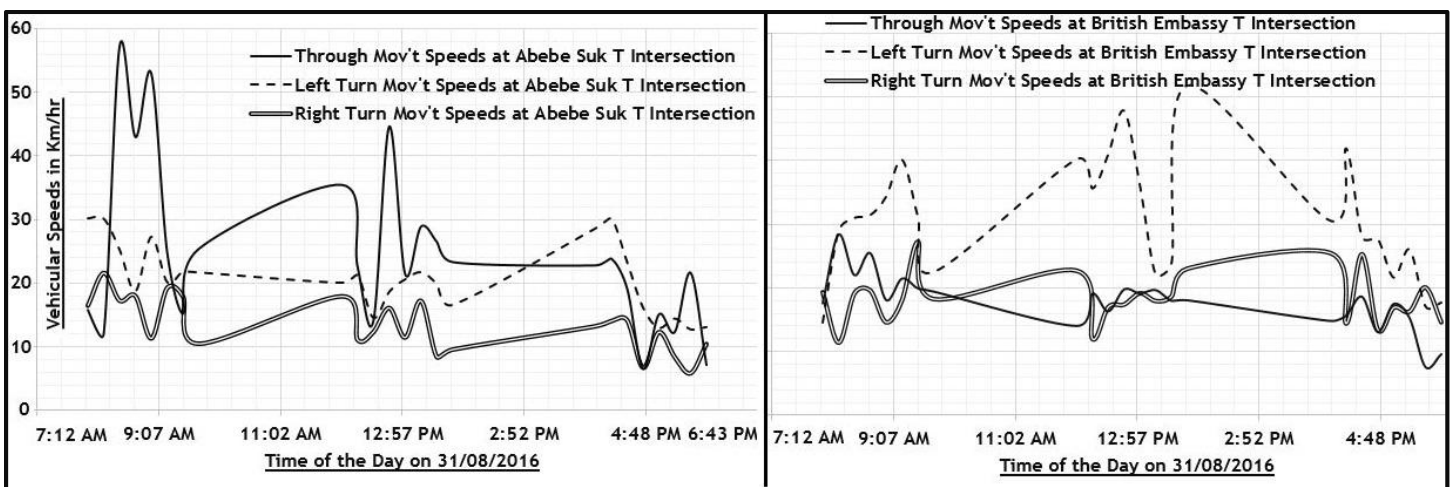
Speed studies can be made usually through two methods. That is, through spot study (time mean speed) and section study (space mean speed). And for this study, section speed study or space mean speed is used for two major reasons:

- ✚ Time mean speed is usually made using equipment and it is somehow difficult to get and make a respective study
- ✚ Space mean speed is better for its ease to conduct and attain average values within a segment

Thus, in the study of *Speeds in Intersections*, the **Left, Through and Right** movement speeds (for cross intersections) and the **Entry, Circulating and Exit** movement speeds (for roundabouts) are studied. Thus, the five intersections in the stretch were assessed and the speed variations are as presented in the **Figures 5.26 to 5.30**. And to study Speeds in Road Segments, the average segment speeds are studied and the speed variations are as presented in the **Figures 5.31 to 5.32**.



**Figure 5.28 & 5.29:** Speed Variations at Diaspora RA and Shola T Intersections (resp.)



**Figure 5.30 & 5.31:** Speed Variations at Abebe Suk T & British Emb. T Inters. (resp.)

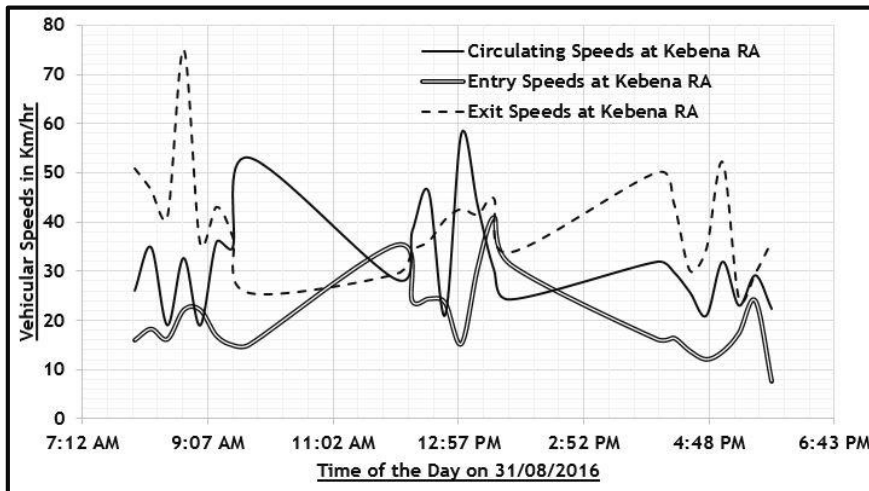


Figure 5.32: Speed Variations at Kebena RA Intersection

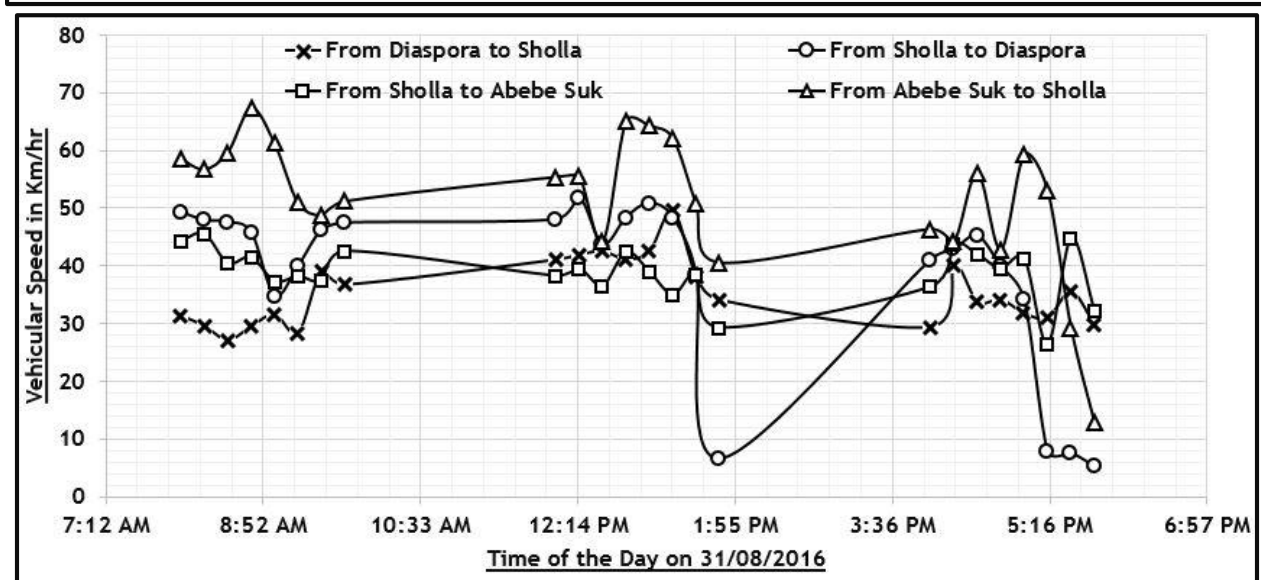
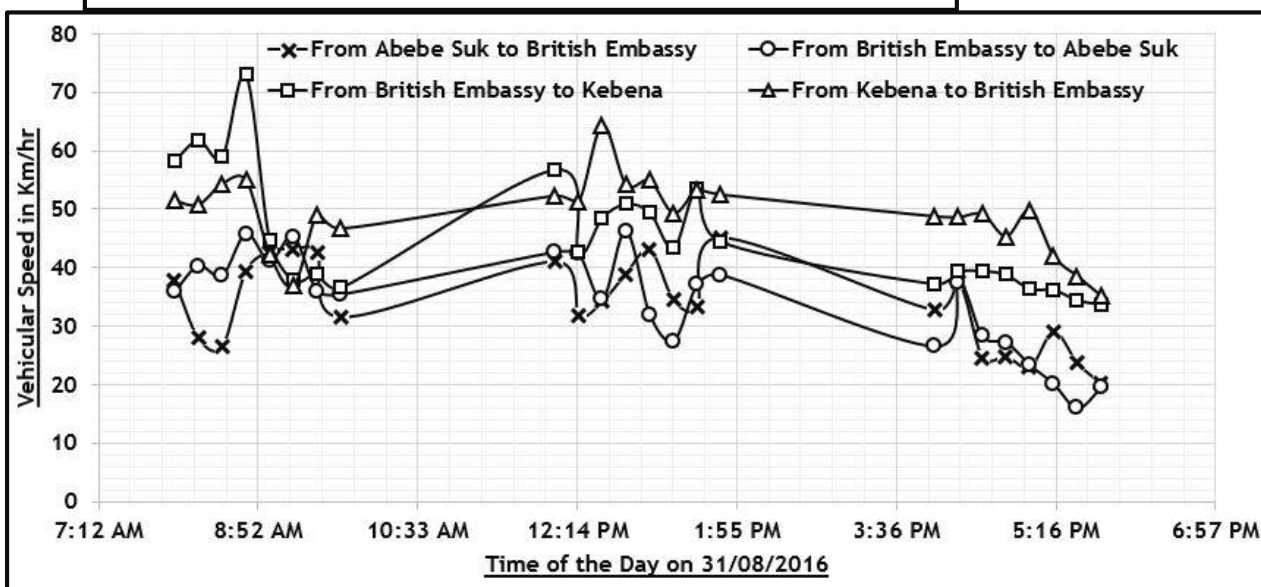
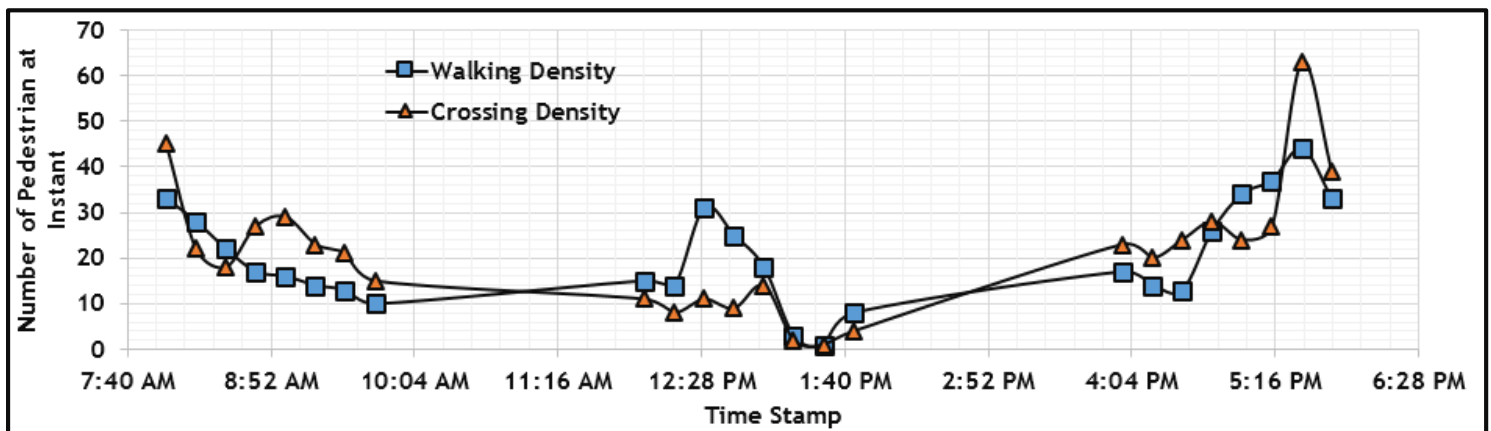


Figure 5.33 & 34: Segment Speed Variations (Top and Bottom)

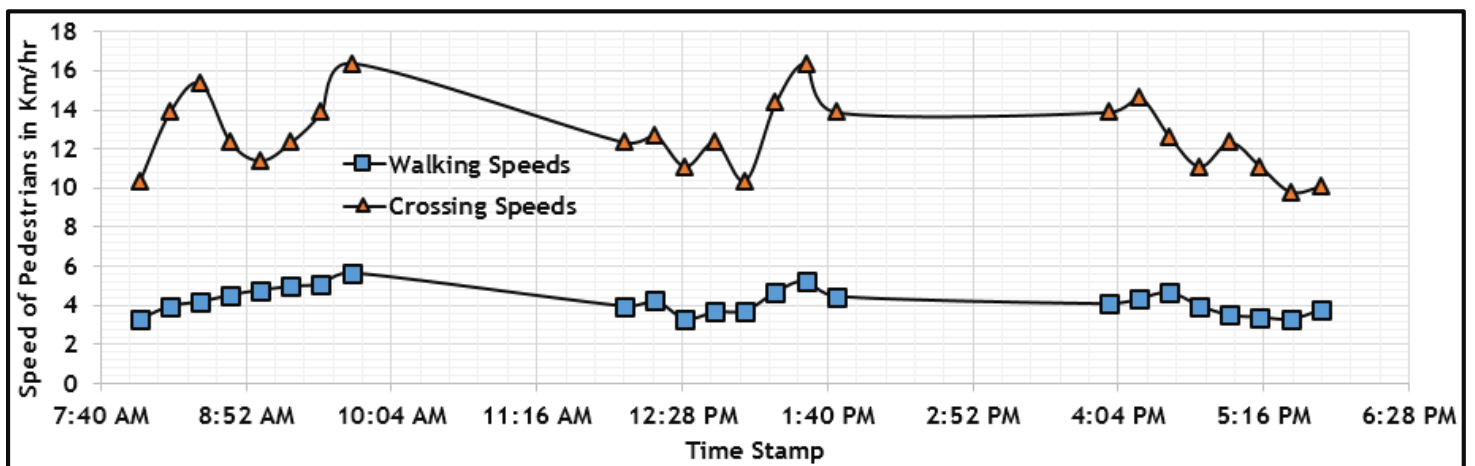
### 5.3. Pedestrian Characteristics Assessment

#### 5.3.1. Pedestrian Speed and Density (Walking and Crossing)

Very close to Diaspora Roundabout (where there is considerable: jay walking, off-street walking and greatest volume of pedestrians), pedestrian speed and density were surveyed. The lowest peak in the density curve shows raining condition. Refer *Figures 5.33* and *5.34* for the details.



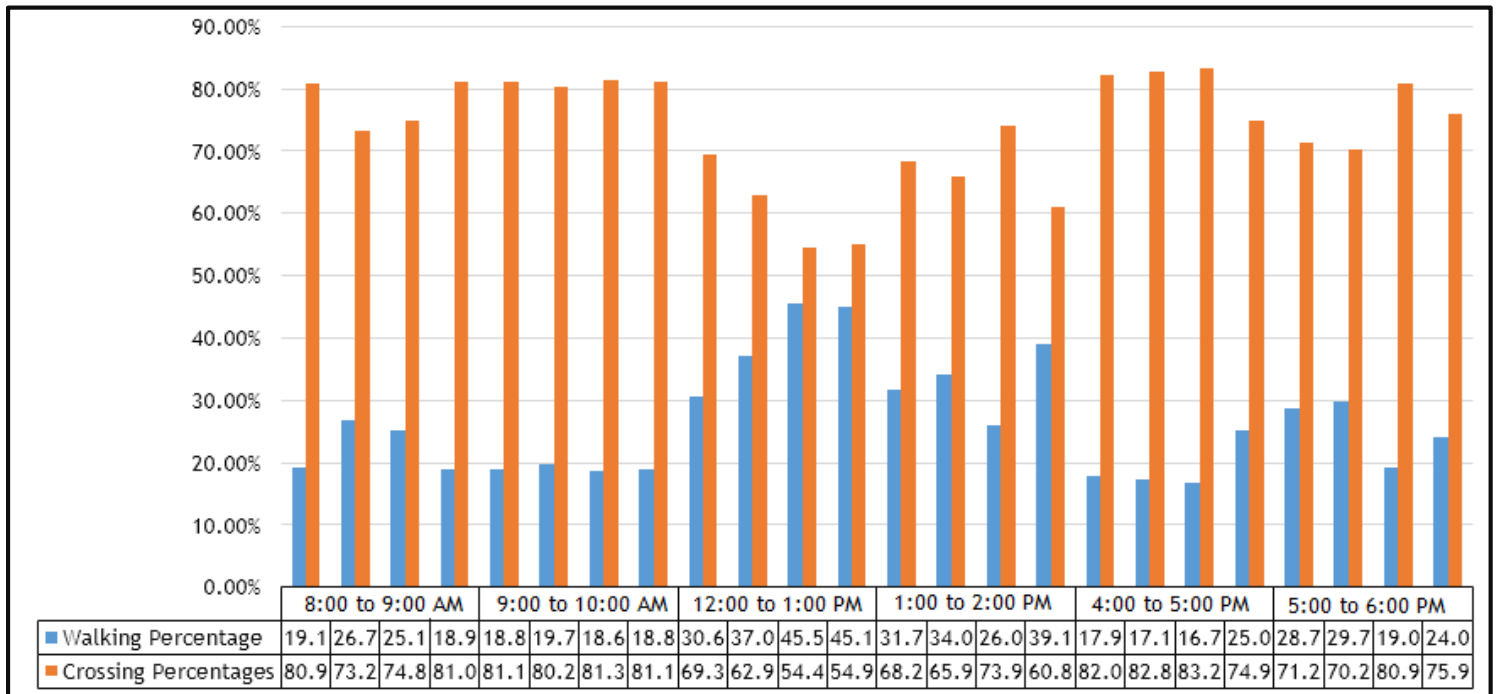
*Figure 5.35: Walking and Crossing of Pedestrians around Diaspora Roundabout*



*Figure 5.36: Walking and Crossing Speeds of Pedestrians*

#### 5.3.2. Pedestrian Volume and Movement Directions

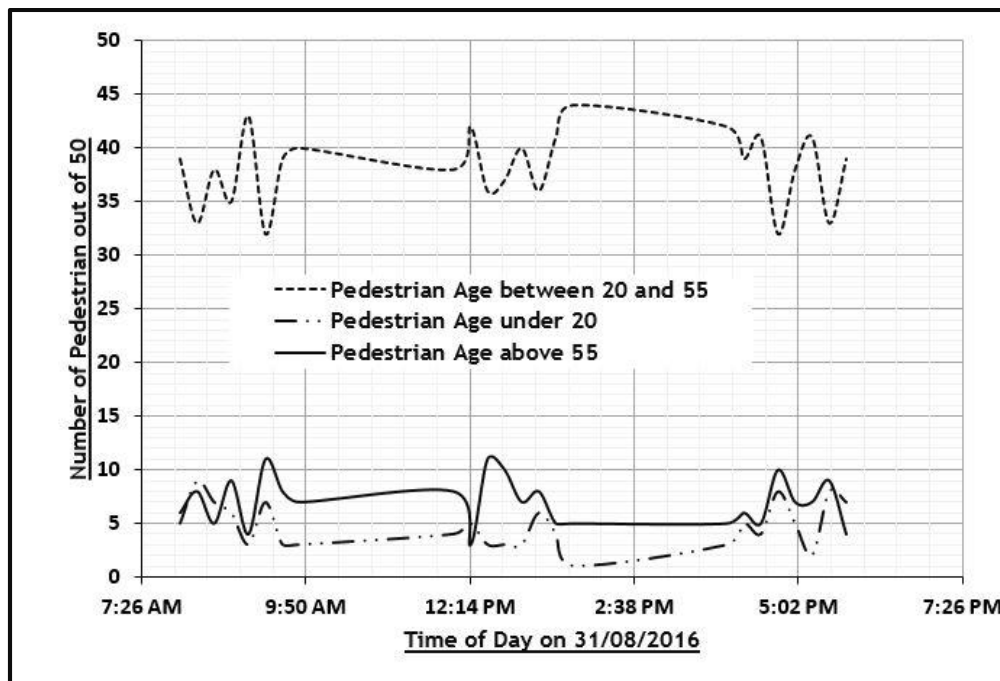
In order to be specific to the objectives of this research, percentage shares of movement types of pedestrians has got due attention. As a result, since pedestrians make crossing decisions in the AM and PM peak periods, impeded movements of vehicles suffer from excessive delays while vehicles arriving on Mid-day traverse with lesser delay. Refer *Figure 5.35* for the variations.



**Figure 5.37:** Variation of Movement Splits of Pedestrians at Diaspora RA

### 5.3.3. Pedestrian Age Groups

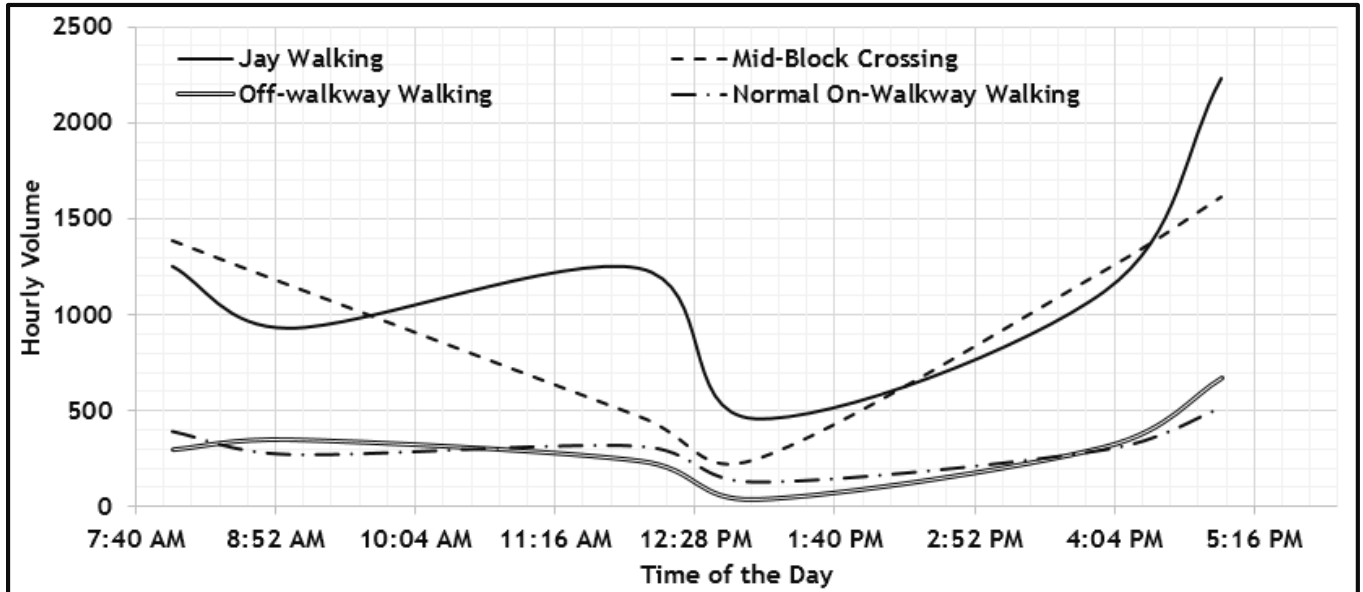
To look on which pedestrians take a share on impeding of vehicular flows, the following was obtained.



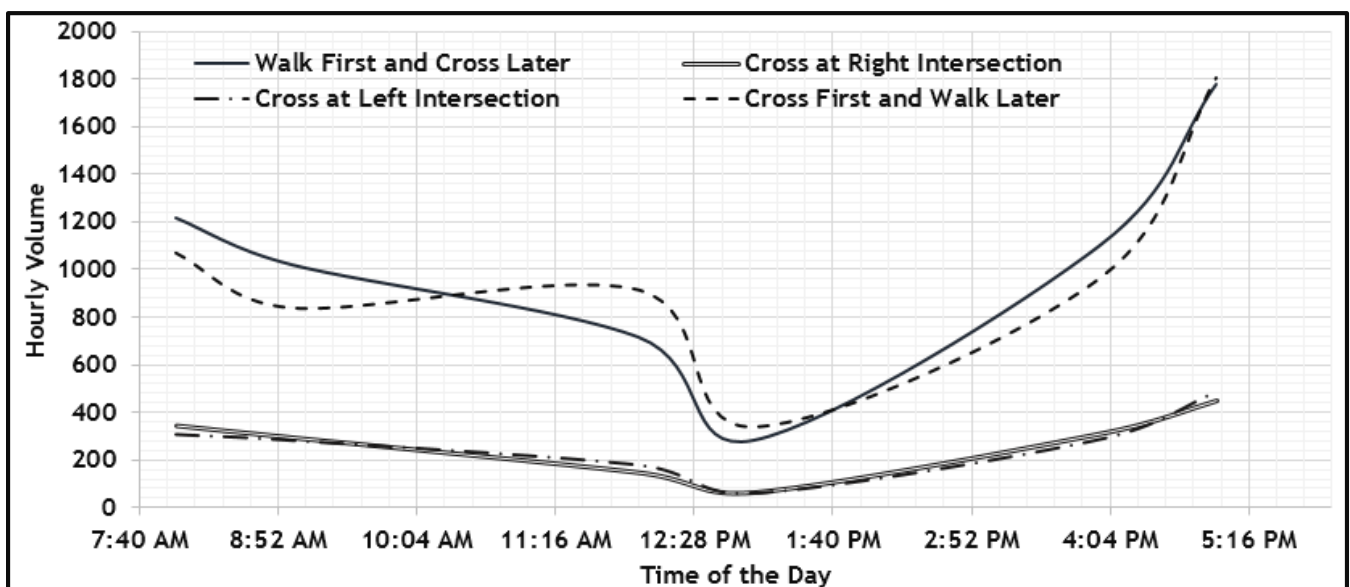
**Figure 5.38:** Variation of Pedestrian Age Group out of 50

### 5.3.4. Pedestrian Trajectory and Crossing

While the concept of pedestrian trajectory is in mind, this research aimed on looking on the shares of every possible types of walking (on and off walkway) and crossing (on crosswalk and at random in jay). The variation is shown in **Figure 5.37**. And furthermore stressing on crossing patterns, the four major types are shown in variation in **Figure 5.38**.



**Figure 5.39:** Variation of Pedestrian Parallel and Crossing Movements



**Figure 5.40:** Variation of Pedestrian Crossing Movements

### 5.3.5. Pedestrian Attitude Survey

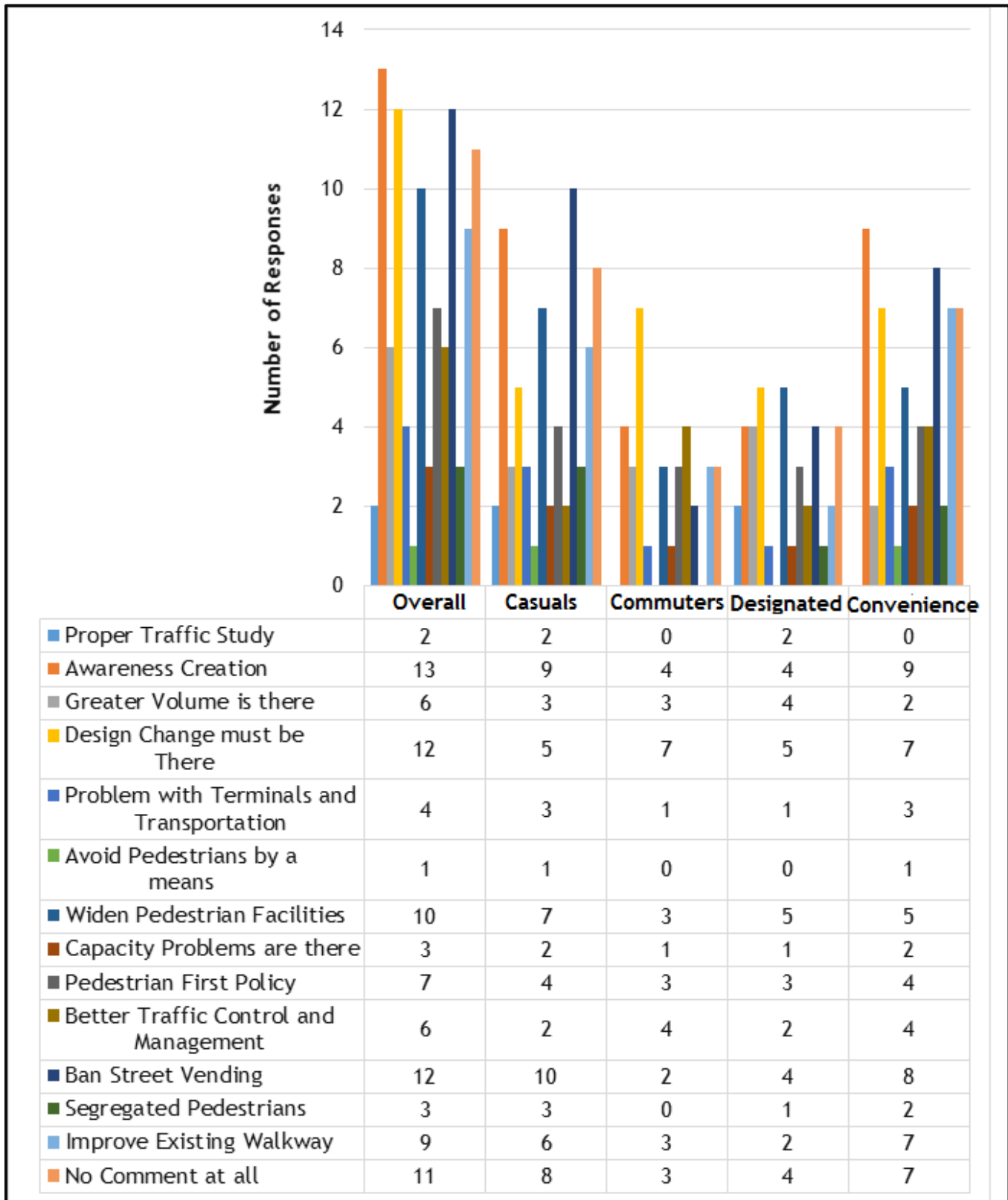
From the pedestrian attitude survey results, the ones that interested most to this research are presented in **Table 5.6** and **Figure 5.39**. As a result, the summary in **Table 5.6** represents the overall responses and the ones highlighted were investigated to be repeatedly responded by surveyed pedestrians.

Moreover, the free comments of pedestrians delineated in **Figure 5.39**, has shown that the four most voiced comments of pedestrians in the area are:

- ✚ Ban of Street Vending in the Area
- ✚ Make of Awareness Creation
- ✚ Redesigning must take place in general and
- ✚ Widening existing pedestrian facilities must be there (as the existing ones were defined more than a decade ago)

**Table 5.6:** Pedestrian Attitude Survey Summary for Overall Assessment

No.	Question		a	b	c	d	e
1	Pedestrian Type	Choice No. of Resp.	Commuter Pass by 12	Casual Pass by 43	Area Commuter 2	Area Casual 3	
2	Pedestrian Facility Rating	Choice No. of Resp.	Highly Convenient 0	Convenient 7	Poor 36	Very Poor 17	
3	Reason for Lower Rating	Choice No. of Resp.	Design 27	Poor Walkway 27	Street Vendors Presence 20	High Pedestrian Volume 31	
4	Attitude on ease of off walkway walking	Choice No. of Resp.	Yes 30	No 30			
5	Attention in the presence of defined crossing locations	Choice No. of Resp.	Yes 21	No 23	I did not notice 16		
6	Crossing Preference	Choice No. of Resp.	At designated crossing location 20	At location of your convenience 40			
10	Major Contributor for the Peak Hour Congestion in the Area	Choice No. of Resp.	Street Vending 22	Greater Demand 25	Lower Capacity 25	Vehicular Interaction 22	Pedestrian Activity 21
11	Effective Measure for the Good of Pedestrians	Choice No. of Resp.	Guard Rail 17	Widening 25	Ban Street Vending 24	Overpass/Underpass Crossing 29	



**Figure 5.41:** Free Comments of Pedestrians

## 5.4. Drivers' Behavior Measurements

### 5.4.1. Lane Changing Behavior

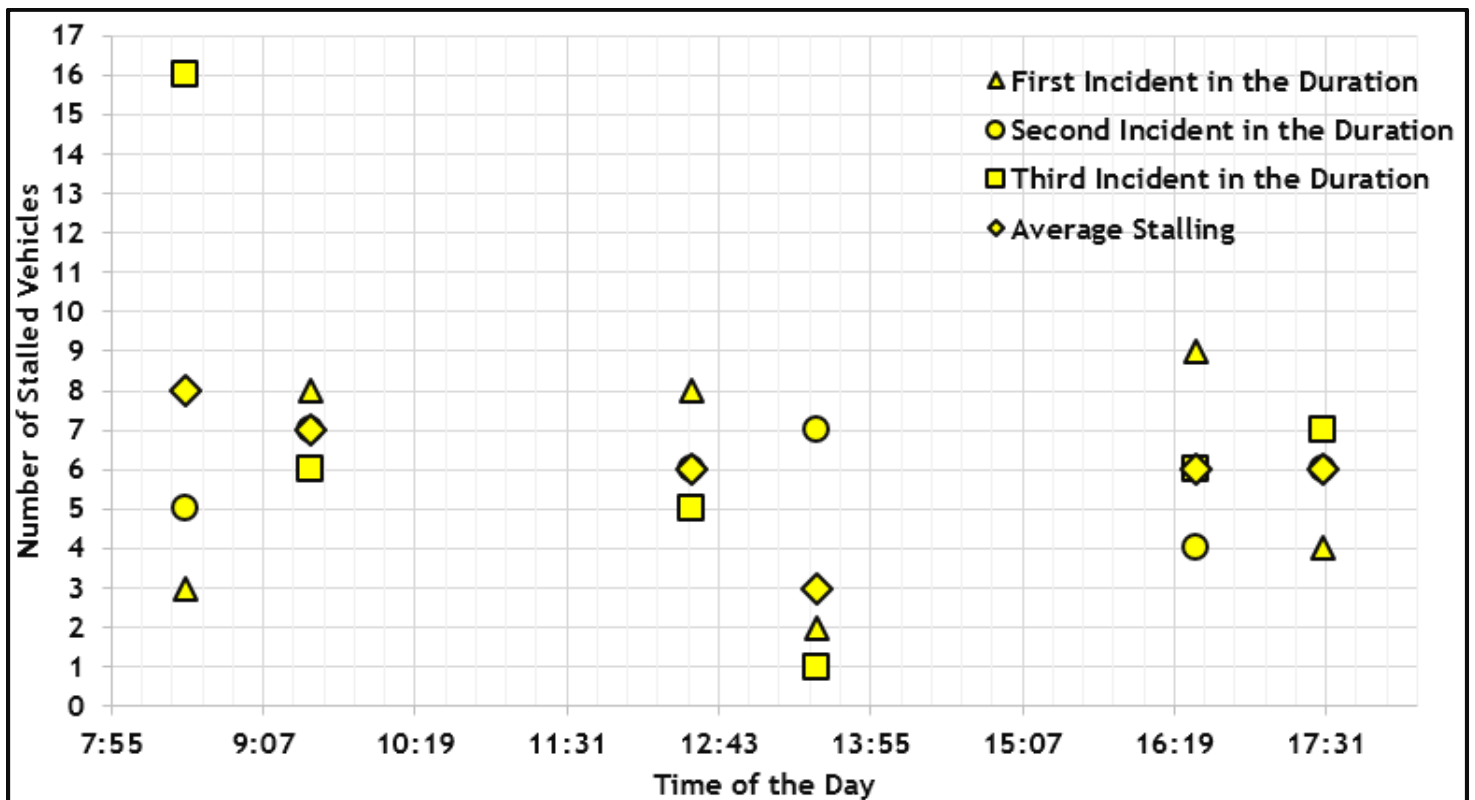
In doing such study, Overtaking is the most viewed case (with the least accepted gap) whilst weaving motion is the least (with the greatest accepted gap). And in addition, overtaking to the right is the dominant one which proves such drivers to be more aggressive. Refer *Table 5.7* for the detail.

*Table 5.7: Lane Changing Behavior of Drivers*

No.	Decision	No. of Surveyed Cases	Average Gap Accepted, in Sec	Standard Deviation, sec	Left Lane	Right Lane
1	Merging	12	3.63	1.14	100.00%	0.00%
2	Overtaking	16	3.57	1.17	43.75%	56.25%
3	Parking	14	15.38	2.3	0.00%	100.00%
4	U-Turn	5	4.49	0.946	100.00%	0.00%
5	Weaving	1	16.11	0	100.00%	0.00%

### 5.4.2. Drivers in Roundabouts

To make this study, the Diaspora Roundabout is assessed for two basic sub-assessments. The first is for the stalled vehicles while following an Articulated Trucks and Buses. The second is by studying throughputs of the roundabout with respect to the arrival rates.



*Figure 5.42: Number of Stalled Vehicles to a Slow Vehicle in RA*

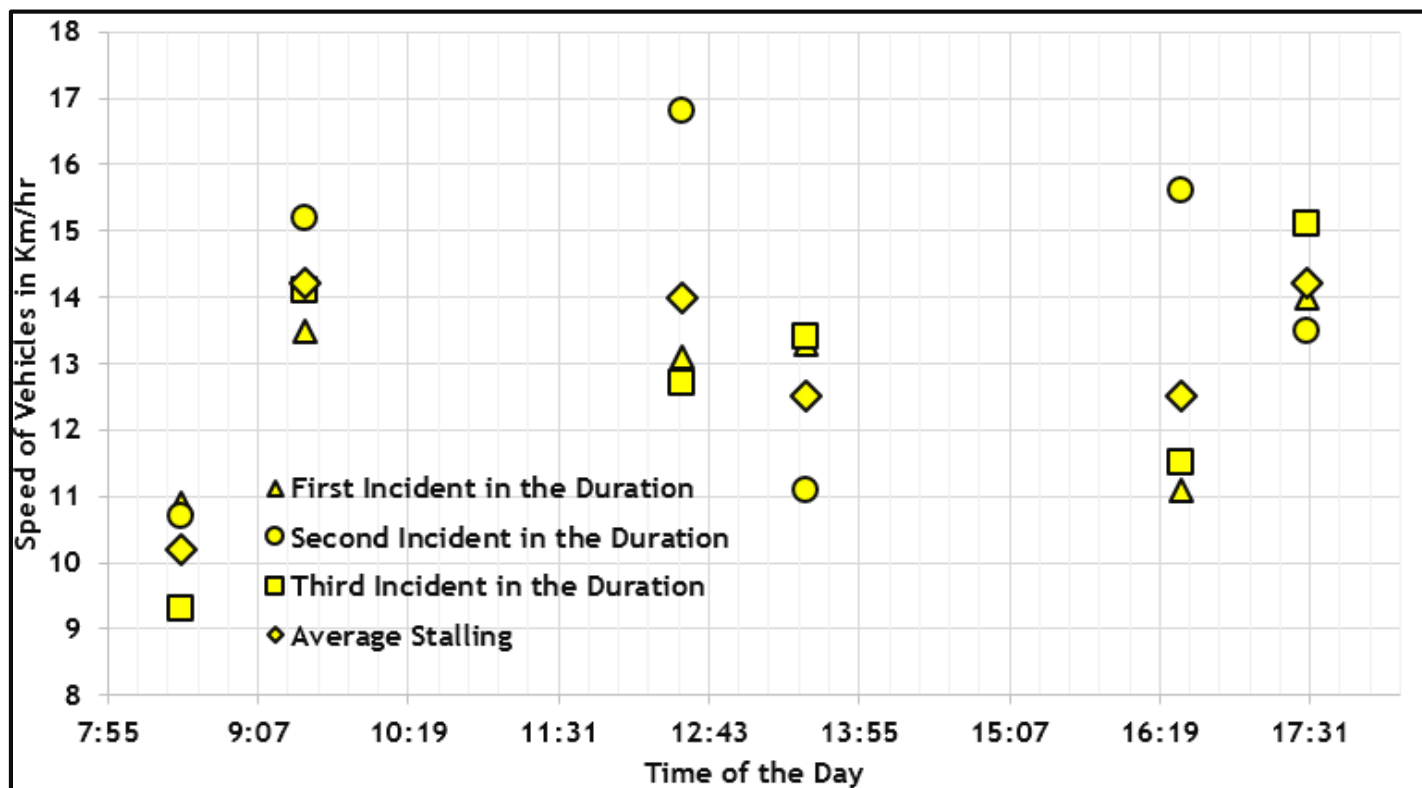


Figure 5.43: Speeds of Stalled Vehicles to a Slow Vehicle in RA

Table 5.8: Effect of Arrival Rate on Throughput at Diaspora RA

No.	Time Interval	Traffic Flow Data		
		Arrival Rate on Shola Gebeya Approach*	Throughput of Roundabout (vph)	Arrival Rate on Other Approaches**
1	8:00 AM - 9:00 AM	0.42	3780	0.39
2	9:00 AM - 10:00 AM	0.46	4003	0.41
3	12:00 PM - 1:00 PM	0.37	3190	0.31
4	1:00 PM - 2:00 PM	0.47	3419	0.27
5	4:00 PM - 5:00 PM	0.5	3867	0.34
6	5:00 PM - 6:00 PM	0.65	4708	0.34

\* Arrival rate of 0.1 is equivalent to 36vph

\*\* Other Approaches than the concerned have equal arrival rates

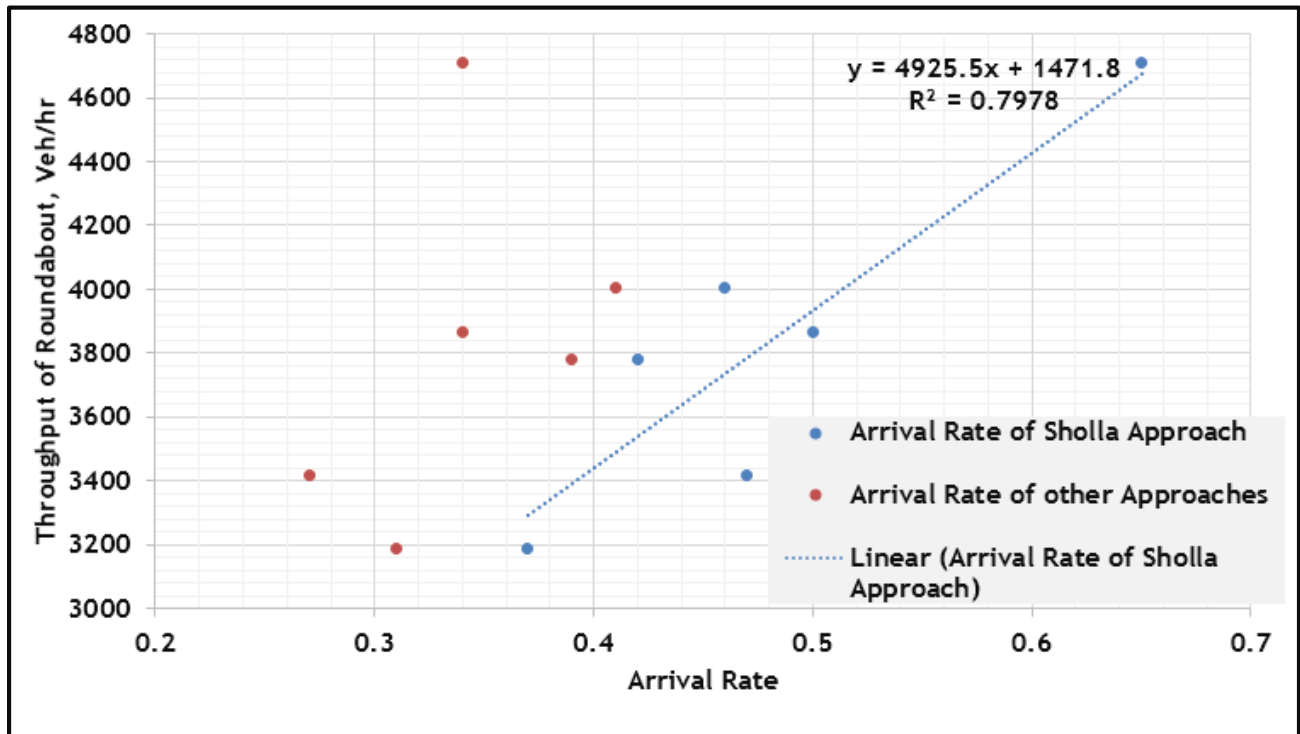


Figure 5.44: Throughput vs. Arrival Rate at Diaspora RA

### 5.4.3. Obstruction Study and Analysis

For this particular study, it was tried to show behavior of drivers after and before they were obstructed by a group of pedestrians. Figure 5.43 and 5.44 can be referred for the detail.

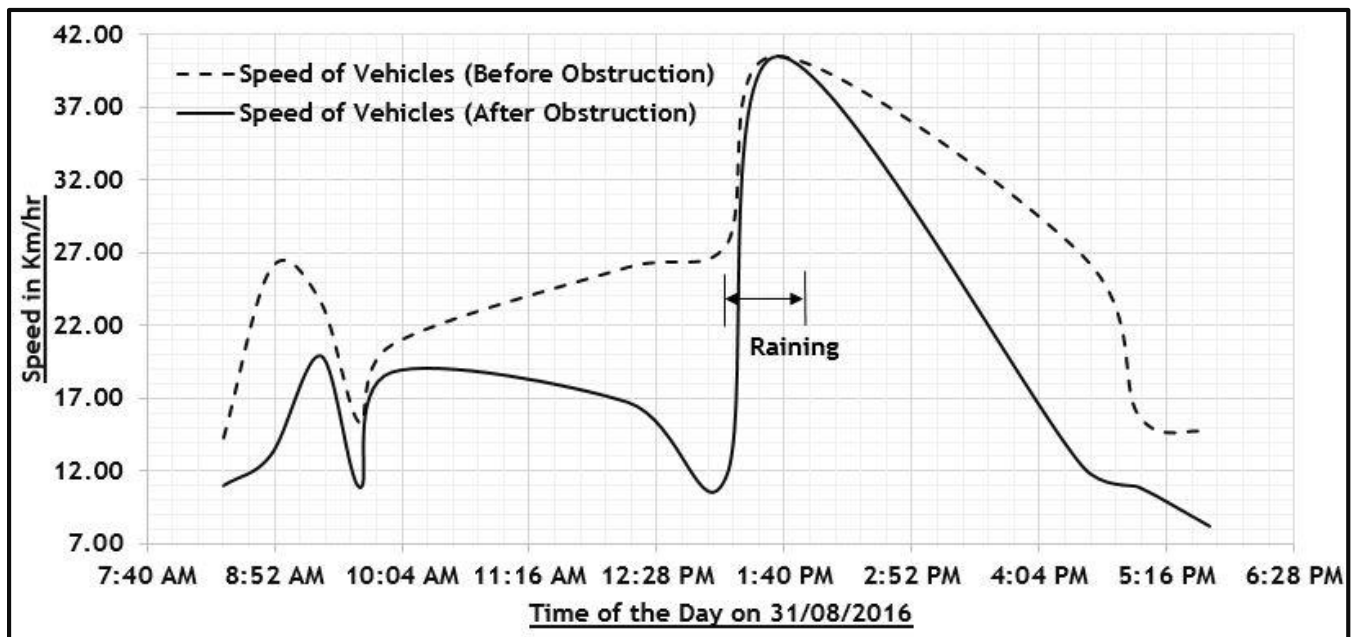


Figure 5.45: Before and After Studies of Obstruction Analysis

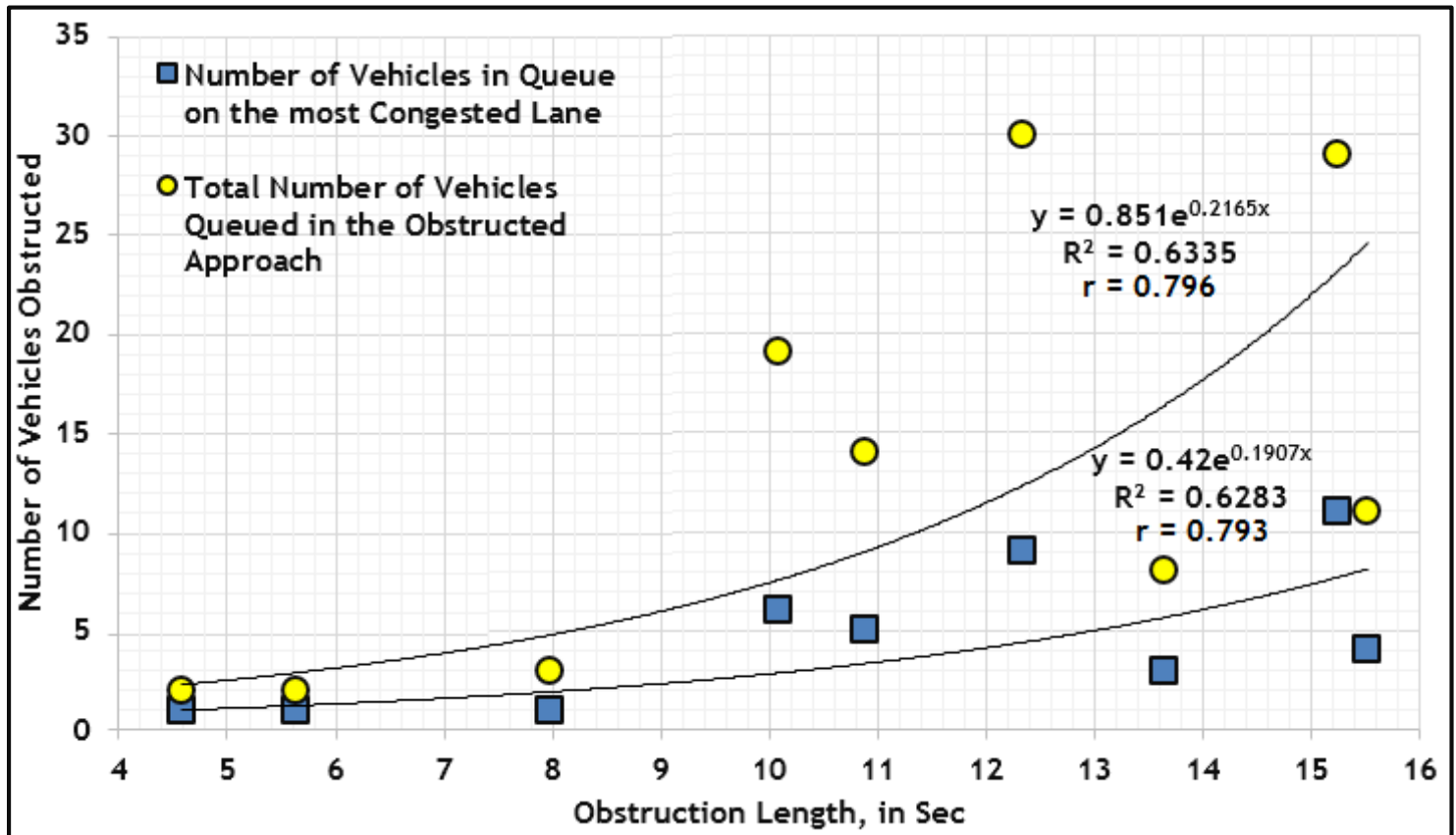


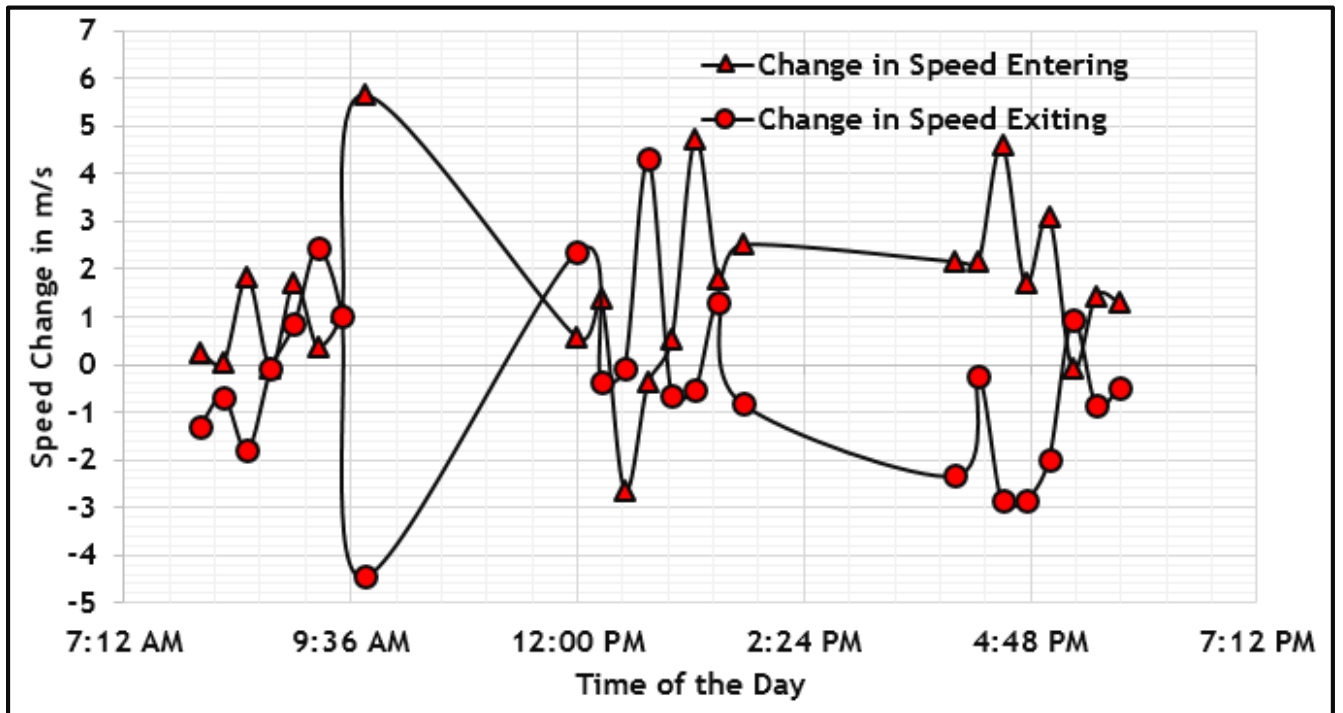
Figure 5.46: Number of Vehicles in Queue vs. Obstruction Length

#### 5.4.4. Acceleration/Deceleration Behavior of Drivers

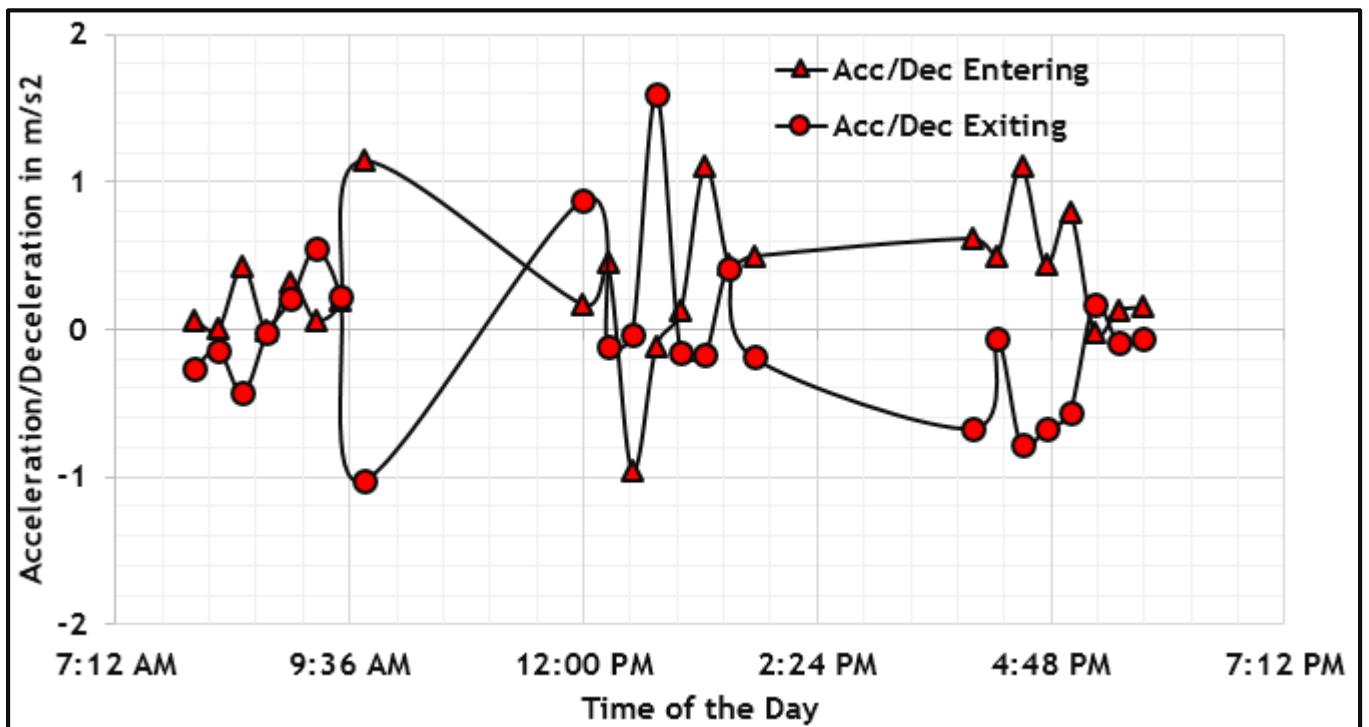
The acceleration or deceleration behavior of drivers was easy to capture while entering and exiting a roundabout. In such a case representative deceleration and acceleration behaviors was captured, respectively. Thus, in the calculation of acceleration/deceleration, the basic physics equation used was:

$$a \text{ or } d = \frac{V_{\text{final}}^2 - V_{\text{initial}}^2}{2 * S}$$

Thus, the speed changes are shown in *Figure 5.45* and the length of speed change in the assessment is  $S = 24.32m$ .



*Figure 5.47:* Speed Changes in Exiting and Entering Diaspora Roundabout

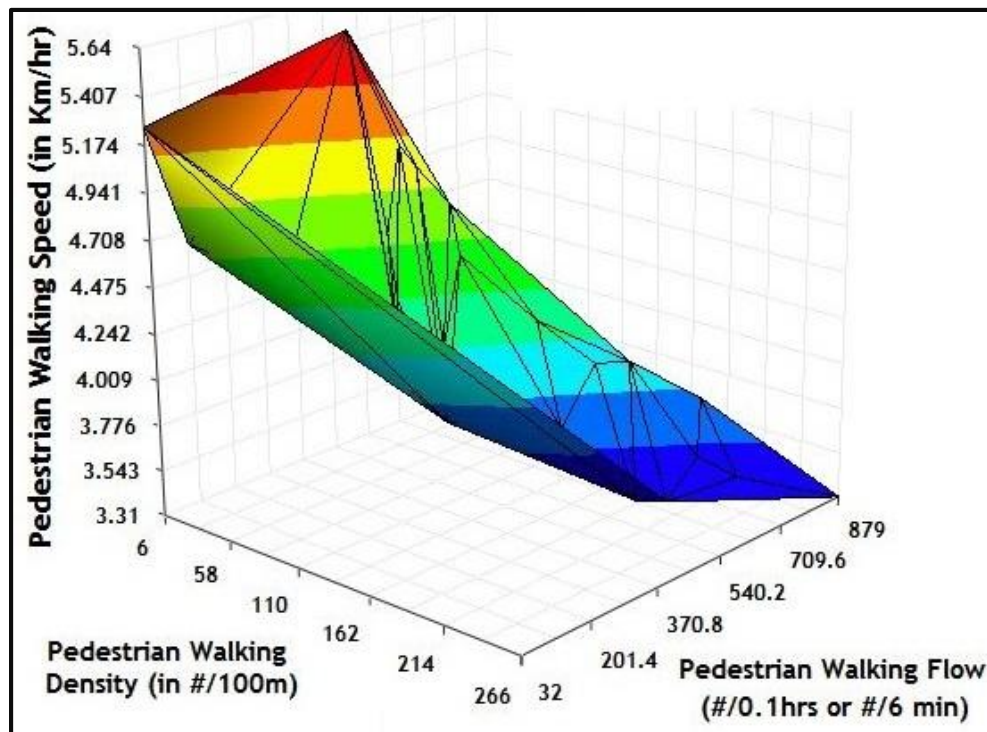


*Figure 5.48:* Acceleration/Deceleration in Exiting and Entering Diaspora Roundabout

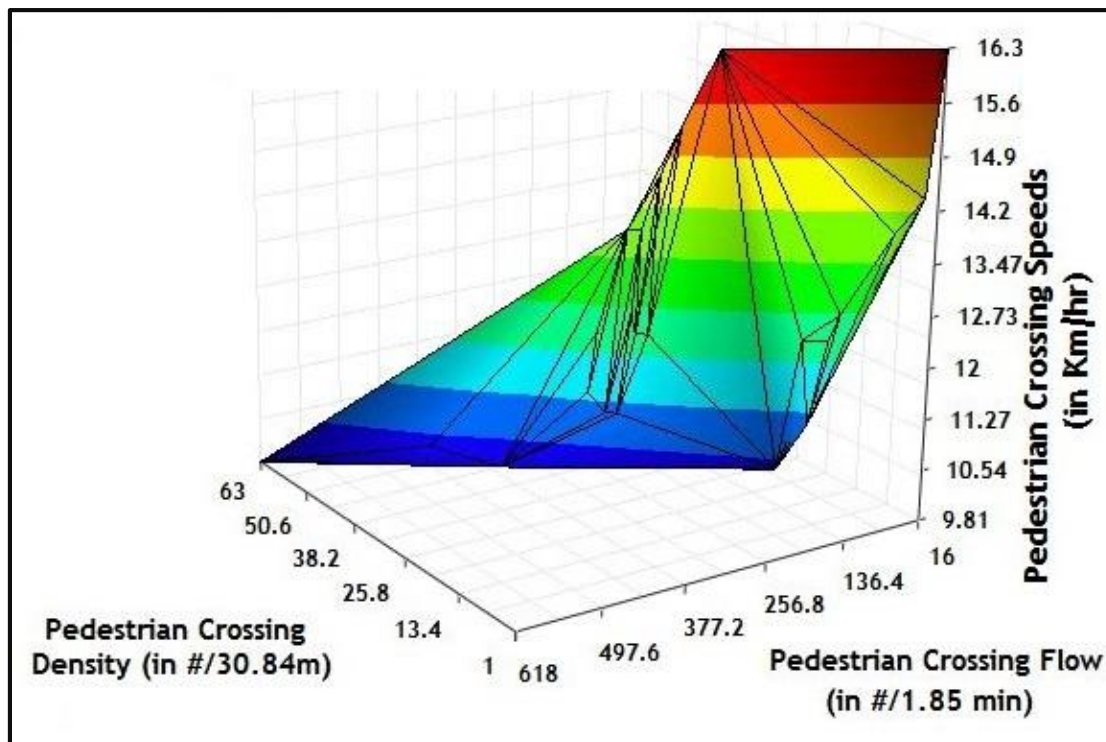
## 5.5. Relationship Analysis of Several Parameters

### 5.5.1. Modeling of Pedestrian Walking and Crossing Movements

Using *Teraplot* software, the following two curves were obtained as to model walking and crossing characteristics. It is presented in *Figures 5.47 & 5.48*, respectively.



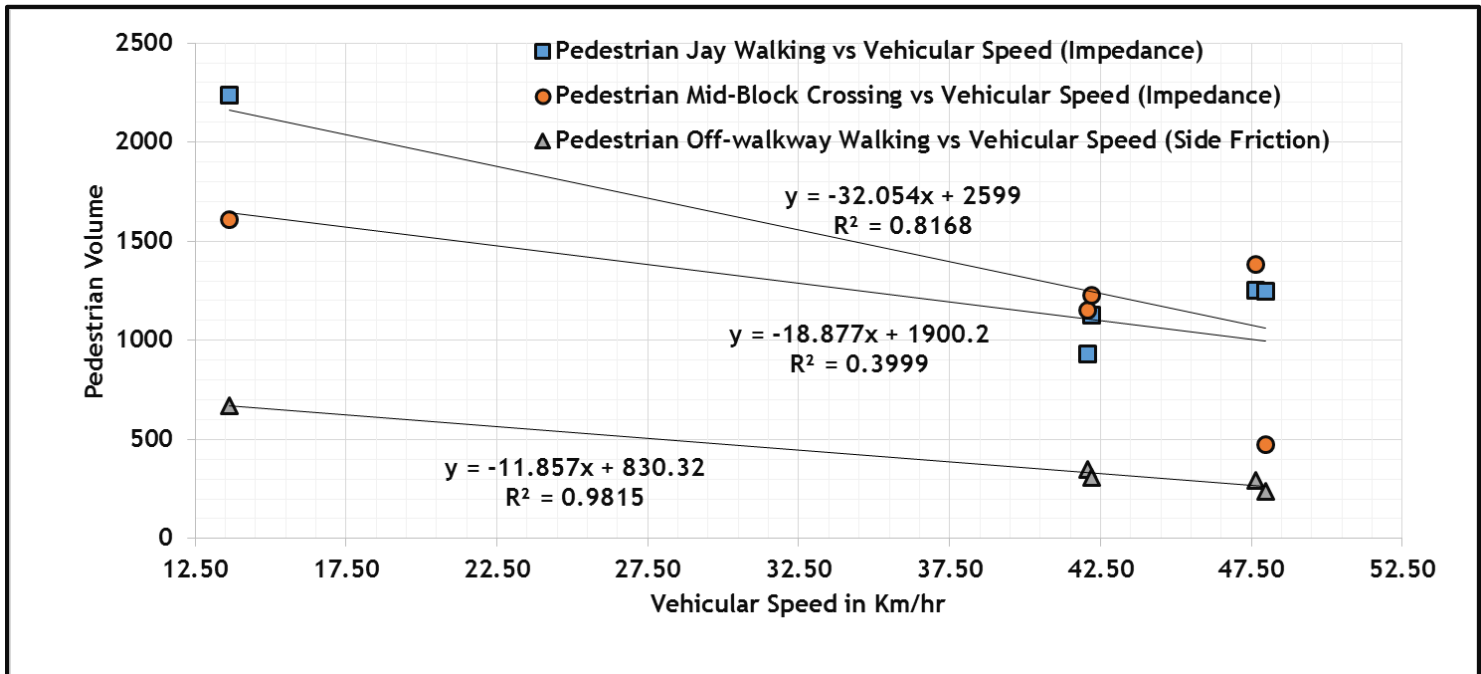
*Figure 5.49:* Density – Flow – Speed 3D Surface Plot of Pedestrian Walking Characteristics



*Figure 5.50:* Density – Flow – Speed 3D Surface Plot of Pedestrian Crossing Characteristic

### 5.5.2. Vehicular Segment Speed vs. Impeding Pedestrian Volume

In *Figure 5.49*, the scatter plots of pedestrian movement volumes in *Jay Walking*, *Mid-Block Crossing* and street vending caused *Off-walkway Parallel movements* are plotted to the vehicular traffic speed in the segment of Shola to Diaspora. And from the linear correlations, we can see that *Jay Walking and Off-walkway Parallel movements are highly correlated on linear relationship to the reducing vehicular speed* on the segment.



*Figure 5.51: Pedestrian Impeding Volume vs. Vehicular Speed*

### 5.5.3. Saturation Flow Rate Vs Demand Flow Rate

After perceiving that there is negative relationship between saturation flow rate and demand flow rates, the best fitting curve for the relationship is cubic with  $r = -0.61$ . But this finding is not to be extrapolated with confidence to other conditions here in Addis Ababa. Anyway, the relationship is presented in *Figure 5.50*.

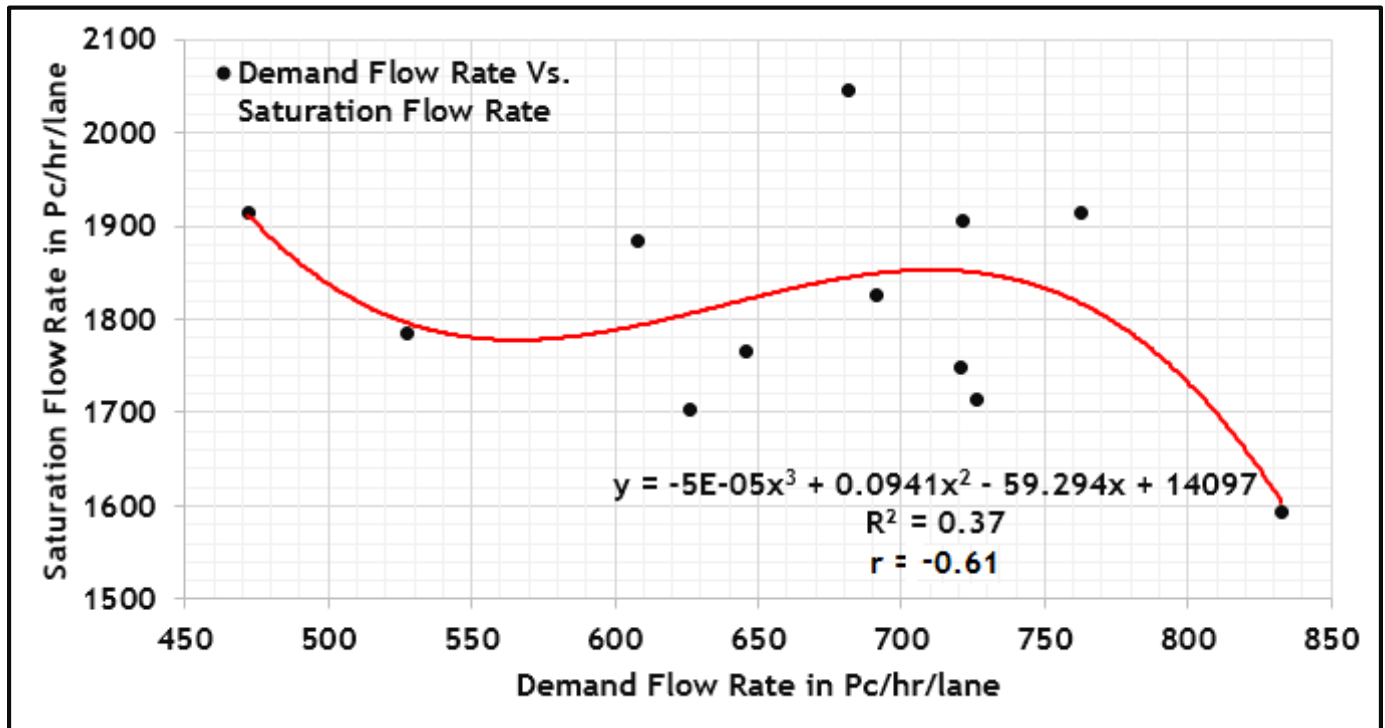


Figure 5.52: Saturation Flow Rate vs Demand Flow Rate

#### 5.5.4. Fundamental Relationships of Traffic Flow

Fundamental relationships are set for three pairs. That is: Speed vs Density, Speed vs Flow and Flow vs Density. Several Researchers have made efforts to develop models for Speed vs Density relationship and they are divided in to four. (Adolph D. May, 1990) [19]

- ✚ Greenshield’s Model (normalizing congested and free states)
- ✚ Greenberg’s Model (best for congested states)
- ✚ Underwood’s Model (best for stable states)
- ✚ Northwestern University Model (best for “S” shaped relationships)

Eight road segments were assessed separately and in overall. And according to **Table 5.9**, **eight of them** are fit best by **Underwood’s model** and the **Shola to Diaspora segment** is best fit by **Greenberg’s model**. This result is ideal in that heavy congestion is inspected here on this segment.

*Development of Models of Interrupted Traffic Flow Conditions of Addis Ababa  
from a Study of an Urban Multi-Lane Highway*

**Table 5.9:** Comparison of Models for Representing Fundamental Flows

Segment	Greenshield's Model		Greenberg's Model		Underwood's Model	
	Equation	R <sup>2</sup> (r)	Equation	R <sup>2</sup> (r)	Equation	R <sup>2</sup> (r)
Diaspora to Sholla	$U_s=56.41 - 1.8222k$	0.73 (-0.85)	$U_s=19.455\ln(69.04/k)$	0.73 (-0.85)	$U_s=62.54e^{-k/19.84}$	0.74 (-0.86)
Sholla to Abebe Suk	$U_s=46.763 - 0.6311k$	0.16 (-0.40)	$U_s=8.1002\ln(1482.23/k)$	0.14 (-0.37)	$U_s=48.95e^{-k/52.63}$	0.19 (-0.44)
Abebe Suk to British Embassy	$U_s=49.754 - 0.9425k$	0.78 (-0.88)	$U_s=16.939\ln(115.51/k)$	0.79 (-0.89)	$U_s=54.92e^{-k/33.11}$	0.81 (-0.90)
British Embassy to Kebena	$U_s=77.156 - 2.4448k$	0.62 (-0.79)	$U_s=31.078\ln(54.07/k)$	0.64 (-0.80)	$U_s=87.17e^{-k/19.27}$	0.66 (-0.82)
Sholla to Diaspora	$U_s=48.05 - 0.4226k$	0.84 (-0.92)	$U_s=16.947\ln(130.89/k)$	0.96 (-0.98)	$U_s=52.98e^{-k/46.73}$	0.92 (-0.96)
Abebe Suk to Sholla	$U_s=66.88 - 1.2717k$	0.66 (-0.81)	$U_s=28.494\ln(67.31/k)$	0.75 (-0.87)	$U_s=80.98e^{-k/24.45}$	0.86 (-0.93)
British Embassy to Abebe Suk	$U_s=49.754 - 1.0305k$	0.85 (-0.92)	$U_s=22.265\ln(87.37/k)$	0.85 (-0.92)	$U_s=66.70e^{-k/28.49}$	0.89 (-0.94)
Kebena to British Embassy	$U_s=77.156 - 1.8484k$	0.36 (-0.6)	$U_s=22.435\ln(104.71/k)$	0.34 (-0.58)	$U_s=79.46e^{-k/24.27}$	0.4 (-0.63)
Overall	$U_s=49.46 - 0.5705k$	0.43 (-0.66)	$U_s=19.971\ln(101.712/k)$	0.616 (-0.79)	$U_s=55.94e^{-k/41.15}$	0.739 (-0.86)

r (+/-)	Correlation
0 - 0.2	No Correlation
0.2 - 0.4	Very Poor
0.4 - 0.6	Poor
0.6 - 0.8	Good
0.8 - 1	Very Good

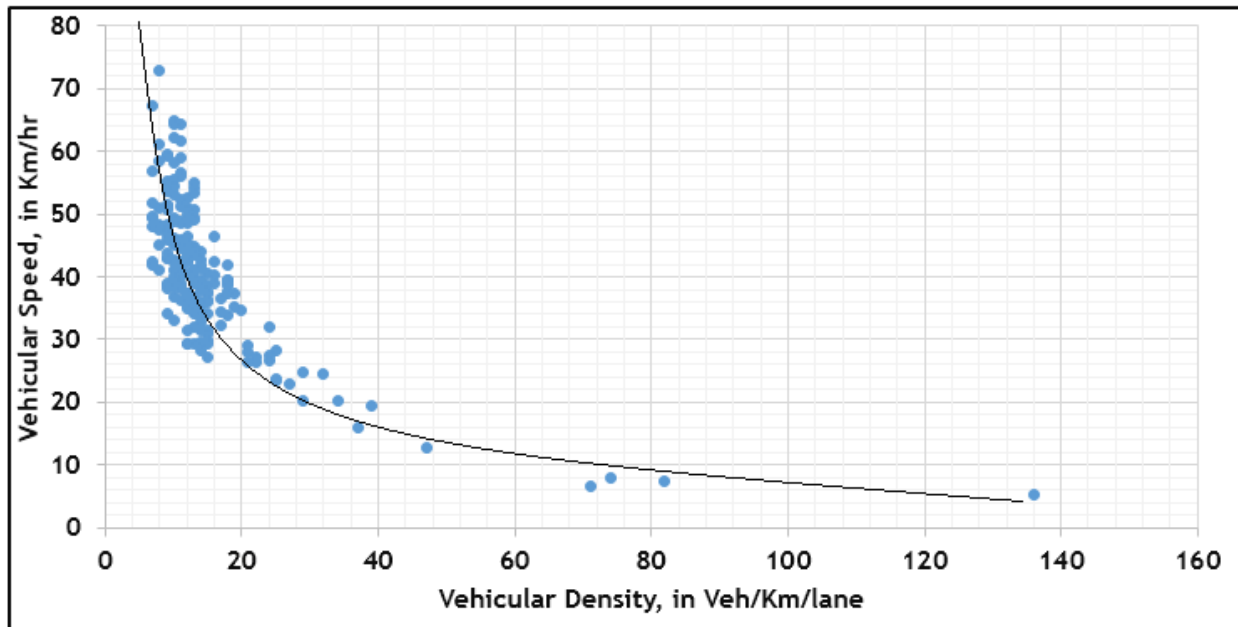


Figure 5.53: Summarized Plot of Speed vs. Density Plot of Eight Urban Multi-lane Highway Segments (the plot has exponential pattern – Underwood’s Model is best Fit)

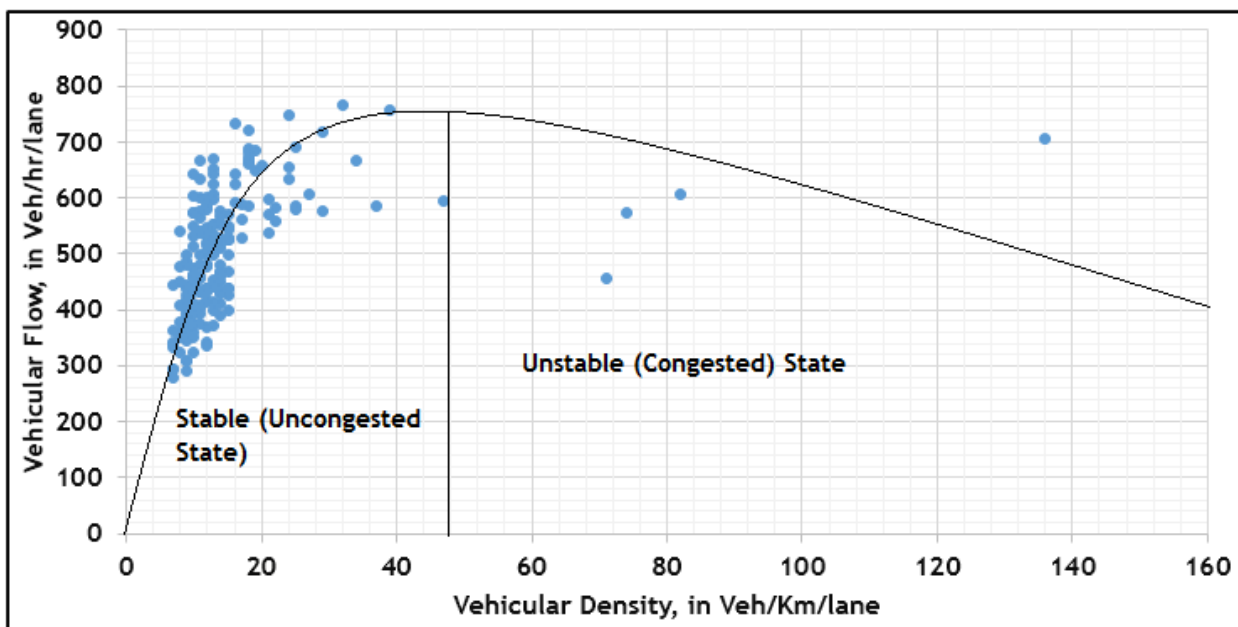


Figure 5.54: Summarized Plot of Flow vs. Density Plot of Eight Urban Multi-lane Highway Segments (most of the points fall in the stable or uncongested portion)

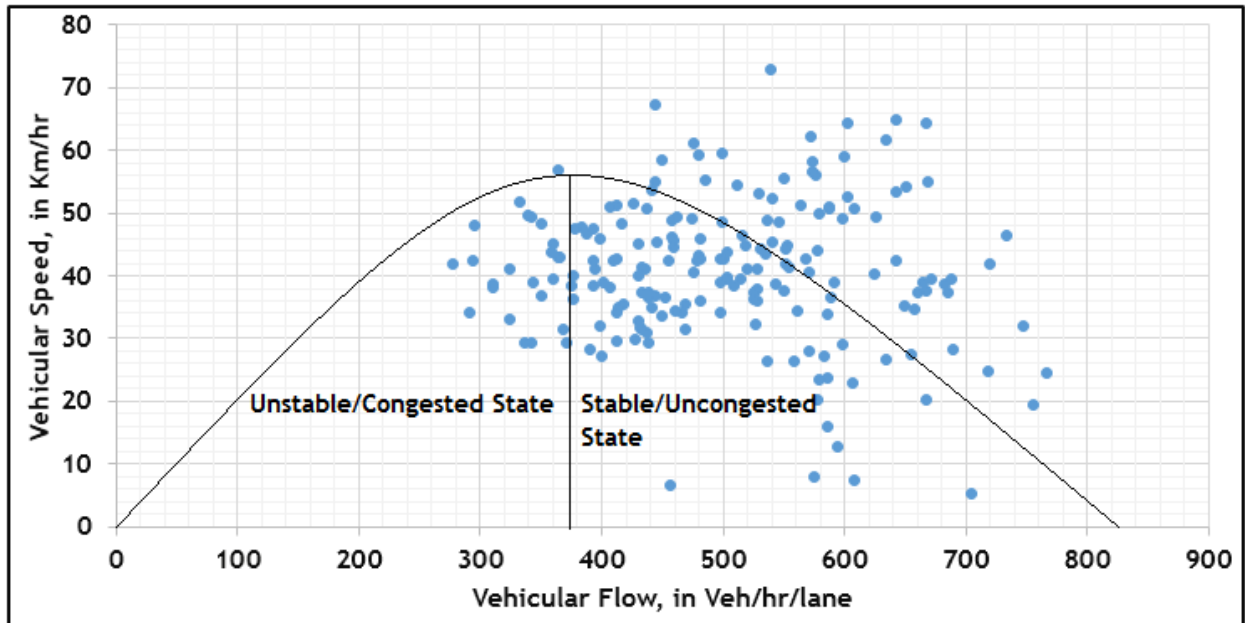


Figure 5.55: Summarized Plot of Speed vs. flow Plot of Eight Urban Multi-lane Highway Segments

### 5.5.5. 3D Surfaces of Density - Speed - Flow Relationships of Vehicular Flows

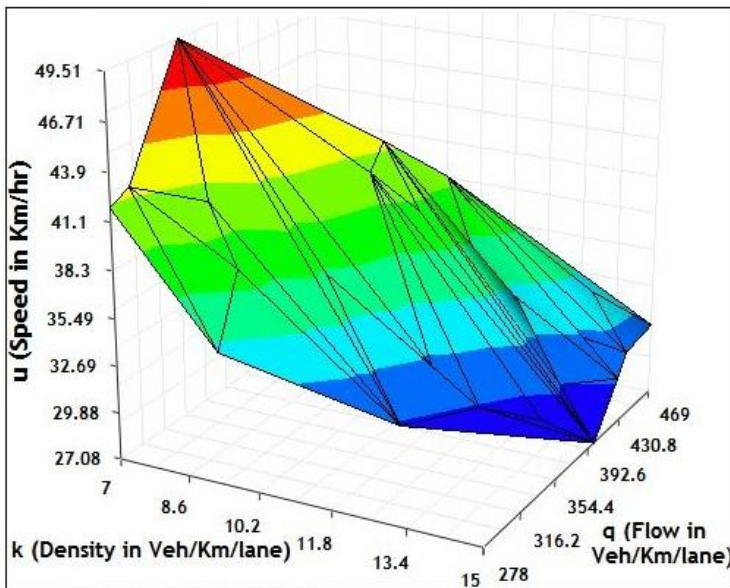


Figure 5.56: k - q - u 3D Surface Plot of Diaspora to Shola Segment (Left)

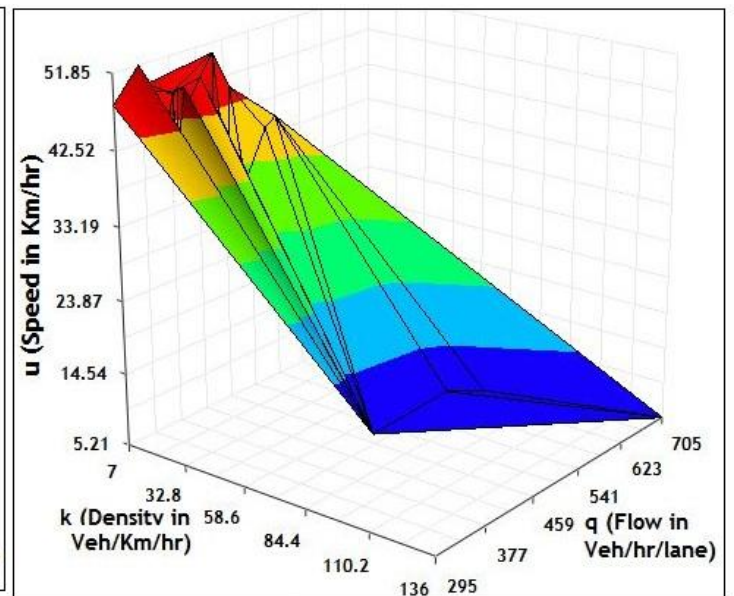
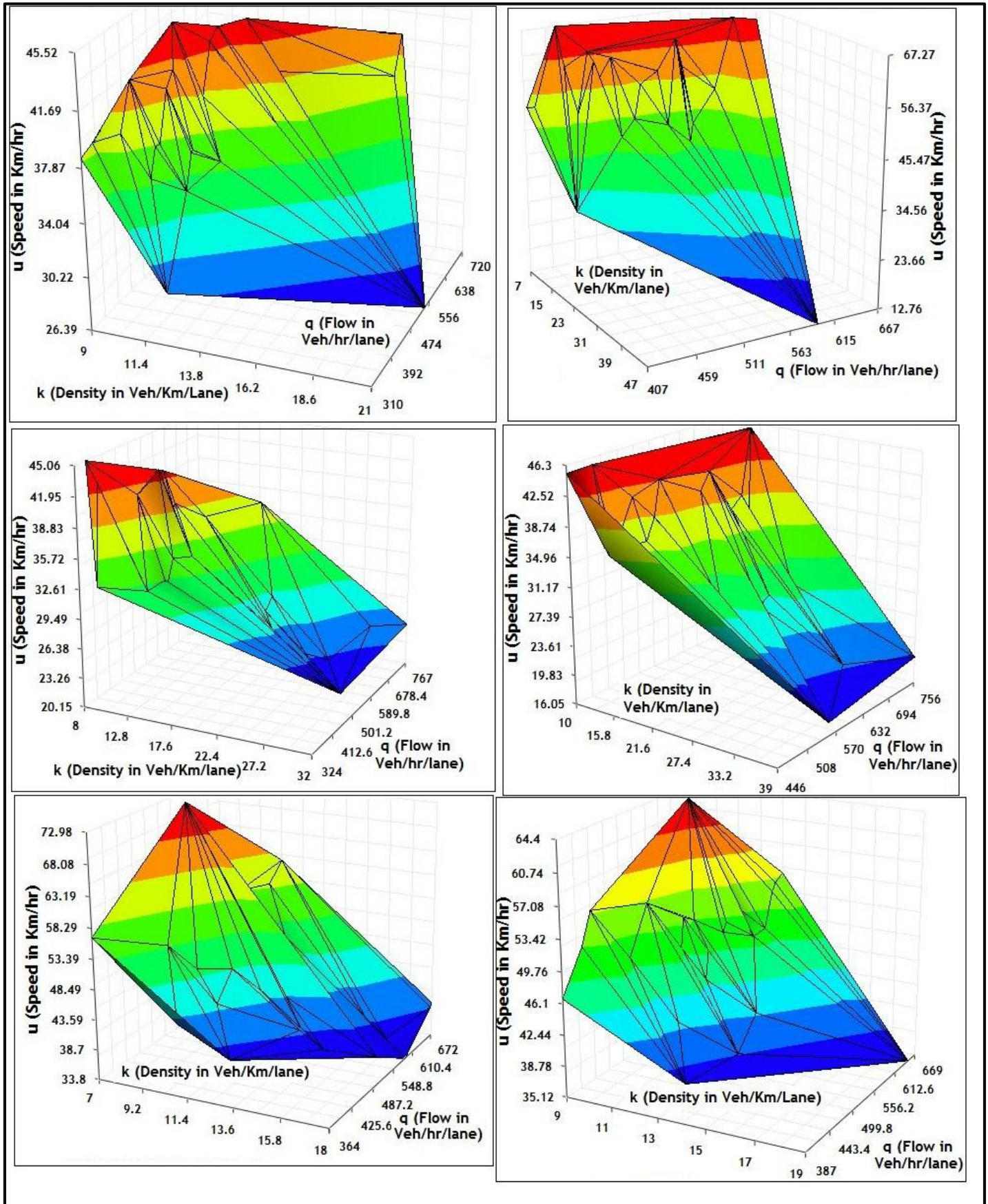


Figure 5.57: k - q - u 3D Surface Plot of Shola to Diaspora Segment (Right)

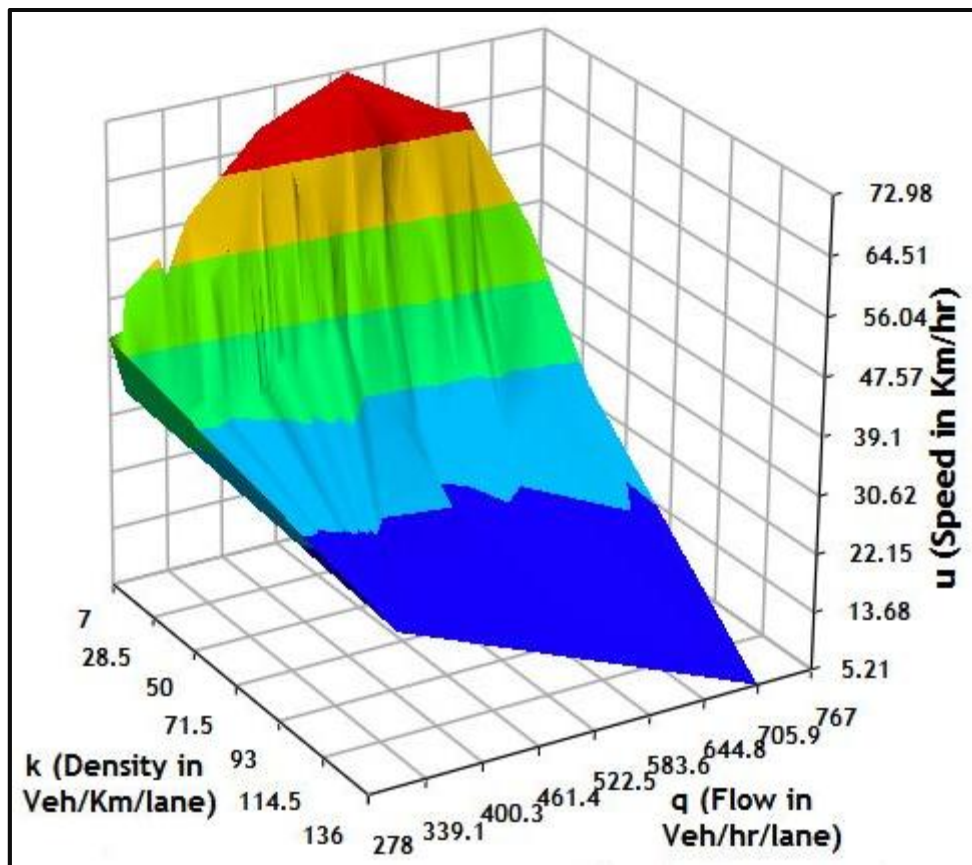
*Development of Models of Interrupted Traffic Flow Conditions of Addis Ababa from a Study of an Urban Multi-Lane Highway*



*Figure 5.58 & 5.59: k – q – u 3D Surface Plot of Shola to Abebe Suk and Abebe Suk to Shola (Top Left and Top Right, respectively)*

*Figure 5.60 & 5.61: k – q – u 3D Surface Plot of Abebe Suk to British Embassy and British Embassy to Abebe Suk (Middle Left and Middle Right, respectively)*

*Figure 5.62 & 5.63: k – q – u 3D Surface Plot of British Embassy to Kebena and Kebena to British Embassy (Top Left and Top Right, respectively)*



*Figure 5.64: k – q – u 3D Surface Summary Plot (proposed to fit Multi-lane highway flows of Addis Ababa)*

## CHAPTER SIX – *INTERPRETATION & VALIDATION OF FINDINGS*

### 6.1. Chapter Introduction

All the research methods, materials, procedure, data and findings are as presented in the previous chapters. Thus, since the main objective of this research is to tell about Addis Ababa's flow conditions, the main findings of this research needs to be interpreted and validated, prior to the research conclusion. Thus, **Section 6.2** will present the interpretation while **Sections 6.3** presents some finding validations.

### 6.2. Interpretation of Results

#### 6.2.1. Effect of Incidents

While studying the effect of incidents on normal stream of traffic flow, **40 cases** were surveyed. Thus, closure of **0 lanes case** was surveyed for 10 vehicles on the approach to **Kebena roundabout** and the other **30 vehicles** were surveyed at the **taxi terminal location** close to **Yeka Subcity Administration Building**.

As a result, two types of cases incurring incidents were observed. The first is **disabled vehicle** and the second is **erratic loading and unloading of taxi drivers**. Taking an average of 10 vehicles for possible number of closed lanes, vehicles with no closure of lanes operate at **61.13 Km/hr**. And as the number of travel lanes reduced from **four to three**, the operating speed has dropped by **25.85%** to **45.33 Km/hr**.

Furthermore, as Taxis make loading and unloading on the second lane, while the outermost lane was occupied, the vehicle speeds drops to **17.52 Km/hr** lessening by **61.35 %**. And while the left most lane is only available (due to the existence of disabled vehicle on the second lane), vehicular speeds are average to **11.67 Km/hr** after dropping by **33.39%**.

Finally, we can be confident that the **95% certain intervals** for operating speeds for closure of **0, 1, 2 and 3 lanes** are **(59.896, 62.364) Km/hr**, **(44.055, 46.605) Km/hr**, **(16.084, 18.956) Km/hr** and **(10.651, 12.689) Km/hr**, respectively.

### **6.2.2. Saturation Flow Rate**

For measuring saturation flow headways, intersections are ideal. Thus, for this research purpose, four intersections were surveyed and **1394** saturation headways were assessed. And in order to tell saturation flow rates in *pc/hr/lane*, **only passenger cars** were observed. As a result, we can be **95 %** sure that saturation headway ranges from **1.9781 to 2.0127 seconds** while the  $q_{sat}$  range from **1789 to 1820 pc/hr/lane**.

Having this mind, it is to be noted that saturation headways **as large as 4.65 seconds** and **as low as 0.57 seconds** was captured. Moreover, the scatter of saturation headways at **Abebe Suk** Area intersection show to be **dispersed** due to the impeding pedestrians in **mid-block crosswalk** in vicinity.

### **6.2.3. Vehicle Seats/Occupancy**

From the perspectives of the research, it was not possible to tell the number of seats taken by passengers in addition to the driver of the vehicles. But rather, the number of **mounted seats** was assessed. Thus, in doing so, **medium buses** with vehicle seats (from 20 to 40) took the least share (**2 %**) while **Automobiles** takes the **greatest (>50%)** share. Finally, vehicles with number of seats ranging from **3 to 12 consists of 91%** of the total vehicle population.

### **6.2.4. Vehicle Composition**

**Three categories** of vehicles were created and **1700 vehicles**, from **five intersections** and respective **approach legs**, were categorized. The sample consists of: **small vehicles (89%)**, **medium vehicles (7%)** and **heavy vehicles (4%)**. Thus, the vehicle population shows on average that **96% are passenger cars while 4% are heavy vehicles**.

### **6.2.5. Vehicular Density**

Vehicular densities observed on the **eight lane two way** study road segment was studied **per direction**. And the **average density** of the four lanes per direction was considered. But it is to be noted that the **inner most lane** entertains **greatest** number of **moving vehicles** while the **outer most** lanes contain **greatest** number of **parked vehicles** (on almost greater stretch of the study segment). The intermediate lanes contain compromised speed and number of vehicles.

As a result, it is to be deduced that on all of the segments **greatest density is observed on the PM peak duration of 5:00 PM to 6:00 PM** as high as **136 Veh/Km/lane** on Sholla to Diaspora Segment (where there exist highest magnitude of impeding pedestrians). On the contrary, lowest density of **6 Veh/Km/lane** was recorded on the Segment from

British Embassy to Kebena in the Mid-Day period from **12:00 to 1:00 PM** (where there is almost none pedestrians impeding vehicular flows).

#### **6.2.6. Time Space Diagrams**

*Two* segments and *four* directions were studied in *three* periods within a day. In the two segments, the smoothness of flow in the two segments are interrupted by the presence of *U-Turn location (Diaspora to Shola)* and *Mid-Block pedestrian crossing (Abebe Suk to Kebena)*.

In addition, weather effects are studied by looking at *Dry, Raining* and *wet* conditions in the *AM, Mid-day* and *PM* peak periods, respectively. And from the set of curves shown in *Chapter Five*, vehicles *approaching* an intersection show *constant time headway* while it becomes erratic as vehicles arrive after *leaving an intersection* which the drivers become *aggressive*.

Moreover, *drivers on raining, wet* and *peak* flow conditions maintain *consistent time headways* while drivers in the *morning* and *dry* conditions perform in a *varied headway conditions* and practicing *least values* of car following times.

#### **6.2.7. Segment Traffic Analysis**

The study segments show that a *consistent* demand flow rate variation within travel lanes (Lanes 1 to 4) is validate for a duration from **8:00 AM to 4:30 PM** while it changes to be *erratic afterwards* till the evening. And based on the observation on site, the *actual level of service* of the road segment *couldn't be validated* by the existing *geometric* and *flow* conditions of the segment, but by the *capacity of intersections* and *impeding movements*. And from the two, *impeding* movements (*off-walkway movement of pedestrians moving away from vending on walkway, simultaneous mid-block and jay walking crossings at two locations, reduced travel lanes due to taxi terminals and interactions between vehicles*) incurs the greatest delay and reduction in service passing the *service breakdown* state way beyond.

As a result, *vehicular queues* reaching to *Shola* at **1.3 Km** distance on *four lanes* is inspected. But on capacity analysis using *Highway Capacity Manual, HCM - 2000* resulted a *LOS of B* on **100%** of the time while the *actual* condition reveals to be *F on peak conditions*. And on the contrary, *British Embassy to Kebena* segment shows to have an *LOS of C* on **67 %** of the time according to *HCM - 2000*, while the actual condition showed a flow condition of *LOS B or greater* due to: the *absence of impeding movements, greater capacity roundabout* ahead and *greater speed* of vehicles.

### 6.2.8. Vehicular Speeds

For studying vehicular speeds, **960 vehicles** were studied for *segment speed analysis* (4 intersections \* 2 directions \* 6 hours \* 4, 15 minute intervals per hour \* 5 sample vehicles) and **360 vehicles** for *intersection speed analysis* (5 intersections \* 3 types of movements \* 6 hours \* 4, 15 minute intervals per hour \* 1 sample vehicle).

**Table 6.1:** Minimum, Maximum and 95% CI Values of Segment Speeds

Segment	# of Sample Vehicles	Std Dev, Km/hr	Avg Speed, Km/hr	Max V, Km/hr	Min V, Km/hr	95% Confidence Interval		
Diaspora to Shola	120	2.57	35.38	60.80	19.46	0.46	34.92	35.84
Shola to Diaspora	120	3.47	38.26	65.72	5.01	0.62	37.64	38.88
Shola to Abebe Suk	120	2.49	38.82	67.34	16.37	0.45	38.37	39.27
Abebe Suk to Shola	120	3.27	51.46	84.57	2.77	0.59	50.87	52.04
Abebe Suk to British E	120	2.86	33.69	58.91	13.09	0.51	33.18	34.21
British E to Abebe Suk	120	2.97	34.12	71.05	12.49	0.53	33.59	34.66
British E to Kebena	120	3.28	45.68	86.26	16.24	0.59	45.09	46.27
Kebena to British E	120	2.71	49.00	80.25	28.52	0.49	48.51	49.49
<b>Overall</b>	<b>960</b>	<b>2.95</b>	<b>40.80</b>	<b>86.26</b>	<b>2.77</b>	<b>0.53</b>	<b>40.27</b>	<b>41.33</b>

**Table 6.2:** Minimum, Maximum and 95% CI Values of Intersection Speeds

Intersection	Movement	Number of Sample Vehicles	Avg Speed, Km/hr	Max Speed, Km/hr	Min Speed, Km/hr	Std Dev, Km/hr	95% Confidence Interval		
Diaspora Roundabout	Circ.	24	22.24	30.64	10.76	5.82	2.38	19.87	24.62
	Entry	24	17.30	36.59	5.57	6.88	2.81	14.49	20.12
	Exit	24	21.30	40.08	7.72	7.64	3.12	18.17	24.42
Sholla Intersection	Left	24	17.12	28.39	8.93	4.04	1.65	15.47	18.77
	Through	24	21.30	31.83	11.33	5.04	2.06	19.24	23.36
	Right	24	18.64	33.41	13.50	4.52	1.85	16.80	20.49
Abebe Suk Area Intersection	Left	24	20.86	30.20	12.77	5.55	2.27	18.59	23.13
	Through	24	24.69	57.07	6.64	13.32	5.44	19.24	30.13
	Right	24	13.36	21.51	5.87	4.19	1.71	11.65	15.07
British Embassy Intersection	Left	24	30.91	51.69	14.54	9.63	3.93	26.97	34.84
	Through	24	17.87	28.38	7.62	4.42	1.81	16.07	19.68
	Right	24	18.43	27.32	11.36	4.16	1.70	16.73	20.13
Kebena Roundabout	Circ.	24	31.72	57.90	19.06	10.25	4.19	27.53	35.90
	Entry	24	20.23	40.82	7.51	7.89	3.22	17.01	23.46
	Exit	24	39.97	74.98	24.42	10.66	4.36	35.61	44.33

And from the above tables, it is evident that **congested** roundabouts are expected to entertain vehicles on average operating speeds of: **circulating - 22.24 Km/hr, entering - 17.30 and exiting - 21.30 Km/hr** while **uncongested** roundabouts are expected to entertain vehicles on average operating speeds of: **circulating - 31.72 Km/hr, entering - 20.23 and exiting - 39.97 Km/hr**.

Moreover, **congested un-signalized** intersections are to experience a **left turning speed - 17.12 Km/hr, through movement speed - 21.30 Km/hr and right turning speed - 18.60 Km/hr**. on the other hand where there is **on-street parking** in the intersection area, **uncongested un-signalized** intersections are to experience a **left turning speed - 20.86 Km/hr, through movement speed - 24.69 Km/hr and right turning speed - 13.36 Km/hr**.

And to tell on the speed variation within a day, **higher speeds** written in the tables above are investigated around **10:00 AM and 1:00 PM** while the **lowest speeds** were experienced from the time **5:30 PM to 6:00 PM**. As the volume variation in the segments is consistent, so is the operating speeds. And we can be **95%** confident that the average speed on **Addis Ababa streets** is between **40.27 to 41.33 Km/hr** (average being **40.80 Km/hr**). But it is to be noted that speeds as **high** as **86.26 Km/hr** and as **low** as **2.77 Km/hr** may be observed.

#### **6.2.9. Pedestrian Speed and Density (Walking and Crossing)**

Very close to Diaspora Roundabout (where there is considerable: **jay walking, off-street walking** and **greatest volume** of pedestrians), pedestrian speed and density were surveyed. The lowest peak in the density curve shows raining condition.

**Crossing** pedestrian density is **greater** than **walking** pedestrian density (on their respective lengths of assessment) on the **AM** and **PM peak** periods. This contributed to the vehicular delay approaching Diaspora Roundabout. Moreover, apparent from their erratic crossing decisions, the **crossing speeds** (average of **12.7 Km/hr**) is greater by **three folds** of **walking speeds** (average of **4.02 Km/hr**).

#### **6.2.10. Pedestrian Volume and Movement Directions**

Pedestrians make **considerable crossing decisions** (**70%** of the total as compared to walking decisions **30%** of the total) in the **AM** and **PM** peak periods. Thus as a result, impeded vehicles on **PM period** suffer from **excessive delays** while vehicles arriving on **Mid-day** traverse with **lesser** delay (without variation on demand flow rate).

#### **6.2.11. Pedestrian Age Groups**

**77.8%** of pedestrians operating on average are **middle aged (20 to 55)**.

### 6.2.12. Pedestrian Trajectory and Crossing

While the concept of pedestrian trajectory is in mind, this research aimed on looking on the shares of every possible types of **walking** (*on* and *off* walkway) and **crossing** (on *crosswalk* and at random in *jay*).

As a result, **Jay Walking** takes **42.27%** of all pedestrian movements (where *all crossings* decisions take **77.8%** of the total). And stressing on walking behaviors, on *average*, *on and off walkway* parallel movements are almost *equal*. But on specific times of the day, this equality is not justified (that is: *off-walkway* walking > *on-walkway* walking on *AM* (**347 off** and **271 on** (**1.29** times)) and *PM* (**669 off** and **518 on** (**1.29** times)) peak periods or *off-walkway* walking < *on-walkway* walking on *AM* (**35 off** and **125 on** (**0.28** times))).

### 6.2.13. Pedestrian Attitude Survey

The free comments of pedestrians has shown that the **four most voiced comments** of pedestrians in the area are:

- ✚ **Ban of Street Vending** in the Area
- ✚ Make of **Awareness Creation**
- ✚ **Redesigning** must take place in general and
- ✚ **Widening** existing pedestrian facilities must be there (as the existing ones were defined more than a decade ago)

The overall response to predetermined choices yielded the following popular responses:

- ✚ The pedestrians are **casual**, most of the time
- ✚ They rate the pedestrian facility to be **poor** and they claim **design & walkway problems** for the lower rating
- ✚ Equivocally, they **support off-walkway** walking
- ✚ They claim that there is **no defined location or do not notice** the presence of **crossing** locations
- ✚ Almost **70 %** of them prefer to **cross** at their **preference**
- ✚ They claim vehicular congestion is due to **capacity - demand** issue
- ✚ They recommend **over/underpass** for the pedestrian movement

### 6.2.14. Lane Changing Behavior

**Overtaking** is the **most viewed** case (with the **least accepted gap - 3.57 sec**) whilst **weaving motion** is the least (with the **greatest accepted gap - 16.11 sec**). And in addition, **what amused the researcher is having drivers overtaking to the right (56.25% of the total) which proves such drivers to be more aggressive.**

### **6.2.15. Drivers in Roundabouts**

Drivers are obliged to follow large slow vehicles while circulating a roundabout with an average speed of **12.3 Km/hr** (50% of the value if heavy vehicle was not present) and such vehicles are to stall **6 vehicles** on average.

Furthermore, an equation to determine throughput of a roundabout for a given varying value of arrival rate of a designated approach (while maintaining the arrival rates of other approaches) is given by:

$$\text{Throughput (in Veh/hr)} = 4925.5 * (\text{Arrival Rate} - 0.1 \text{ being } 36 \text{ veh/hr}) + 1471.8,$$
$$R^2 = 0.798, r = 0.91$$

### **6.2.16. Obstruction Study and Analysis**

For all the cases, when drivers are obstructed by a group of pedestrians crossing on mid-block crosswalks, the **speed after obstruction is 60% of the speeds of vehicles before** such interruption. It is also to be noted that the **queued vehicles increase exponentially depending on the length of obstruction.**

### **6.2.17. Acceleration/Deceleration Behavior of Drivers**

In doing such study, vehicles that are **entering a roundabout by reducing** their speed to merge circulating traffic **tend to increase their speed to a very great value** as they **depart or exit** the given roundabout. This relationship is **negative but linear** with greater correlation.

### **6.2.18. Modeling of Pedestrian Walking and Crossing Movements**

**Pedestrians walking speeds** range from **3.31 Km/hr to 5.64 Km/hr**, while their **density** and flow ranges from **6 pedestrians/100 m to 266 pedestrians/100 m** and **32 pedestrians/6 min to 879 pedestrians/6 min**, respectively.

On the other hand, **Pedestrian crossing speeds** range from **9.81 Km/hr to 16.3 Km/hr**, while their **density** and **flow** ranges from **1 pedestrians/30.84 m crosswalk to 63 pedestrians/30.84 m** and **16 pedestrians/1.85 min to 618 pedestrians/1.85 min**, respectively.

### **6.2.19. Relationship between Pedestrian Impedance vs. Vehicular Speed**

In **Section 5.5.2**, we have tried to see the scatter plots of impeding pedestrian movement volumes in **Jay Walking (Impeding or conflicting movement)**, **Mid-Block Crossing (Impeding or conflicting movement)** and street vending caused **Off-walkway Parallel movement (Side friction or frustrating movement)** to the vehicular traffic

**speed** of the segment Shola to Diaspora. Thus, a **strong negative linear correlations** are acquired but **Jay Walking** and **Off-walkway Parallel movements** have the greatest coefficient of determination and correlation coefficient values. That is:  **$R^2 = 0.817$  ( $r = - 0.904$ ) for Jay Walking** and  **$R^2 = 0.982$  ( $r = - 0.991$ ) for Off-walkway Walking.**

### 6.2.20. Saturation Flow Rate Vs Demand Flow Rate

After perceiving that there is **negative relationship** between saturation flow rate and demand flow rates, the best fitting curve for the relationship is **cubic with  $r = -0.61$** . And this equation is only good for demand flow rate range of **400 to 900 pc/hr/lane**, for the bizarre **constant** acquired in the equation.

### 6.2.21. Fundamental Relationships of Traffic Flow

Based on 3D modeling of the three fundamental relationships, it can be deduced that:

- ✚ **Flows** as high as **767 Veh/hr/lane** and as low as **278 Veh/hr/lane**, was found
- ✚ **Speeds** as high as **72.98 km/hr** and as low as **5.21 Km/hr**, was recorded
- ✚ **Densities** as high as **136 Veh/Km/lane** and as low as **7 Veh/hr/lane**, was looked

Thus, two equations are forwarded for stable and unstable flow states in Addis Ababa.

$U_s = 19.971 \ln(101.712/k) \quad R^2 = 0.616$ $(r = - 0.79)$	$U_s = 55.94e^{-k/41.15} \quad R^2 = 0.739$ $(r = - 0.86)$
<b>For Unstable or Congested Flow States</b>	<b>For Stable or Uncongested Flow States</b>

## 6.3. Validation of Results

### 6.3.1. Simulation Modeling using PTV VISSIM 9.0

As it was mentioned in the Research Methods, Material and Procedure chapter, simulation modeling was perceived to be conducted using **PTV VISSIM version 9.0**. Thus, it was tried to conduct simulation modeling using the student version. But the following limitations were experienced:

- ✚ Size 1 x 1 km
- ✚ No pedestrians
- ✚ Compromised Interface
- ✚ No 3D Studio Max export
- ✚ No Synchro interface
- ✚ Max. 600 simulation seconds

Thus, by the above limitations, **we cannot validate the undertaken strategic modeling using such simulation modeling.**

# Development of Models of Interrupted Traffic Flow Conditions of Addis Ababa from a Study of an Urban Multi-Lane Highway

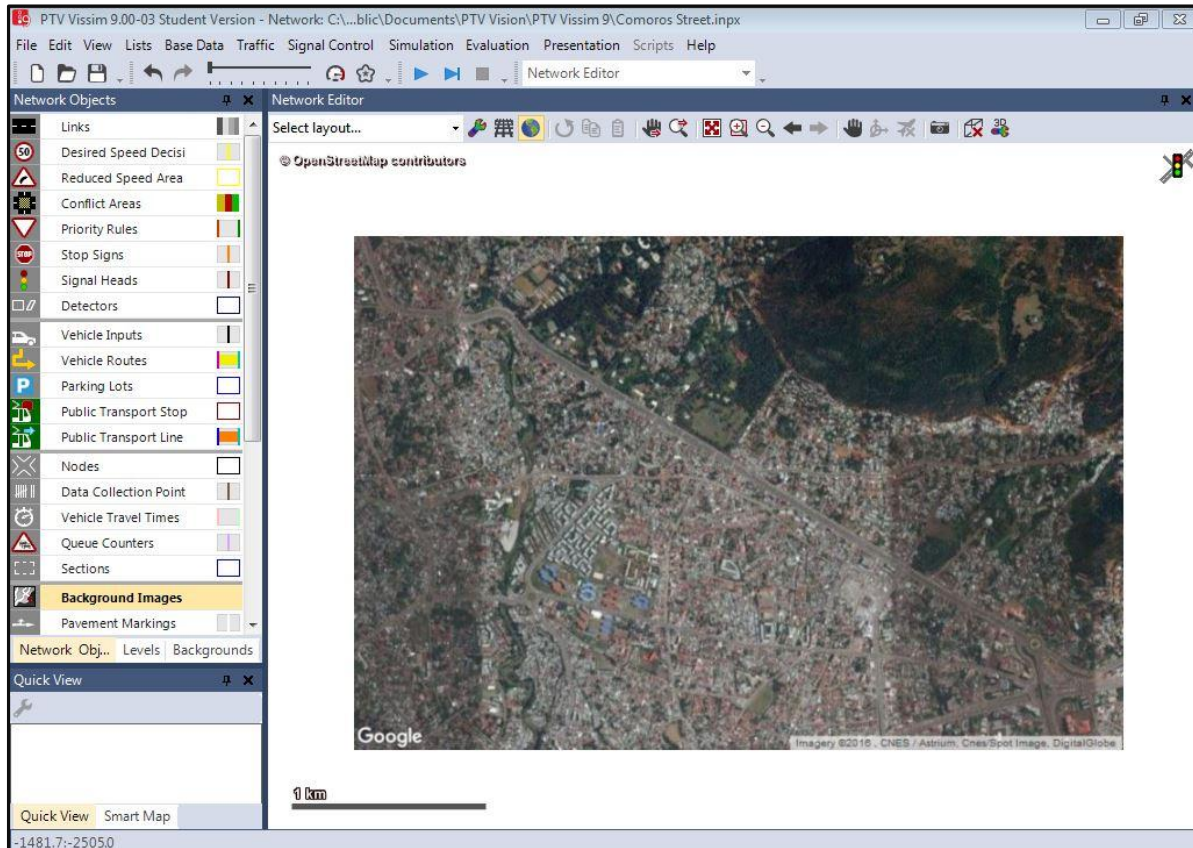


Figure 6.1: the PTV VISSIM 9.00 Software Interface with the Research Image Background



Figure 6.2: Study Locations for Major and Validation Assessments

### 6.3.2. Major Research Model Tests in Addis Ababa

In this section, not on exhaustive terms, it was tried to demonstrate the validation of major outcomes of the research. On more directions, the researcher recommends detail validation expeditions for further verifications. *Eri Bekentu and Yohannes Intersections* (location shown in *Figure 6.2*) are investigated hereunder.

#### 1. Saturation Flow Rate

In *Section 5.2.2*, it was determined that the typical saturation flow rate for Addis Ababa ranges from **1789 to 1820 Pc/hr/lane**. And as of *Table 6.3*, it was demonstrated that sample saturation flow rates of *Yohannes* and *Eri Bekentu* Intersections (which are un-signalized) are **1716** and **1867 Pc/hr/lane**. Which their average falls in the above range. Thus, we validate this research’s saturation flow rate estimate of Addis Ababa, particularly for un-signalized intersections.

*Table 6.3:* Validation of Saturation Flow Rate Values

Sample Headway	Location	
	Yohannes Intersection (headways, sec)	Eri Bekentu Intersection (headways, sec)
1	2.18	1.79
2	2.13	1.98
3	2.64	2.13
4	1.6	1.77
5	1.94	1.97
<b>havg</b>	<b>2.098</b>	<b>1.928</b>
<b>qsat</b>	<b>1716</b>	<b>1867</b>

#### 2. Vehicular Speeds

On the road segment from *Eri Bekentu to Parliament*, five vehicles were sampled to survey their respective speeds in traversing a **196m** section. In the meantime, the density was measured and the observed and predicted speeds (using the equations in *Section 5.5.4*) are as summarized in *Table 6.4*.

Since the flow state during the study was stable, the developed *Underwood’s Model* was more precise in approximating the results. That is: *Underwood’s Model* showed in **4.5%** discrepancy than the *Greenberg’s Model* (**5%**).

And the average speed obtained is **41.69 Km/hr** very close to the one recommended for Addis Ababa (**40.8 Km/hr**) in *Section 6.2*.

Therefore, we validate this research’s recommended operating speeds and traffic flow modeling of Addis Ababa.

**Table 6.4:** Eri Bekentu Vehicular Speeds and Model Testing

Density	5	Veh/196m/lane	
	14	Veh/Km/lane	
Vehicle	t, sec	L, m	V, Km/hr
1	18.29	196	38.58
2	12.75	196	55.34
3	16.54	196	42.66
4	18.24	196	38.68
5	18.81	196	37.51
t <sub>avg</sub> (sec)		<b>16.93</b>	
V <sub>avg</sub> (m/s)		<b>11.58</b>	
V <sub>avg</sub> obs (Km/hr)		<b>41.69</b>	
V <sub>avg</sub> est (Km/hr)		<b>39.81 Underwood's Model</b>	
V <sub>avg</sub> est (Km/hr)		<b>39.60 Greenberg's Model</b>	

**3. Saturation Flow Rates vs. Demand Flow Rate**

In *Section 5.5.3*, it was stated that it is *difficult* to determine *Saturation Flow Rate (qsat)* from Measured *Demand Flow Rate (Vd)* values. Thus, at *Eri Bekentu*, the cubic equation developed was tested and the result is as shown below.

$$Vd = k*U = 14 \text{ Veh/Km/lane} * 41.69 \text{ Km/hr} = \underline{\underline{584 \text{ Veh/hr}}}$$

$$Qsat = -5 \times 10^{-5} * X^3 + 0.0941 * X^2 - 59.294 * X + 14097$$

$$Qsat = \underline{\underline{1604 \text{ Pc/hr/lane}}}$$
 (lesser by 263 of 1867 Pc/hr/lane)

Thus, we cannot validate the relationship developed between *Saturation Flow Rate (Qsat)* and *Demand Flow Rate (Vd)*.

**4. Pedestrian Walking and Crossing Behaviors**

At *Yohannes un-signalized intersection*, walking and crossing speeds of sample pedestrians were assessed. As a result, from this research, only *walking behavior* is *very close* to the ones observed around *Diaspora Roundabout*. The *crossing speeds* here are less than the range observed at *Diaspora Roundabout*.

**Table 6.5:** Yohannes Intersection Walking and Crossing Speeds

Ped #	L (m)	t (sec)	Crossing Speeds (Km/hr)	L (m)	t (sec)	Walking Speeds (Km/hr)
1	19	13.27	5.15	22	16.73	4.73
2	19	15.38	4.45	22	15.13	5.23
3	19	9.95	6.87	22	19.74	4.01
4	19	11.57	5.91	22	15.75	5.03
5	19	10.69	6.40	22	14.65	5.41
Avg Cro. Speed			<b>5.76</b>	Avg Walk. Speed		<b>4.88</b>

## CHAPTER SEVEN: *CONCLUSION AND RECOMMENDATIONS*

### 7.1. Conclusion

On current dates, most metropolitan areas in the world are experiencing traffic congestion during commuting hours, more than any time. And to alleviate such inconvenience, authorities aim on planning of infrastructure projects, in upgrading and/or in constructing new facilities. But, this action faces four challenges. Most of the time these challenges are: very high cost, lack of space, a harmful effect on the environment and/or it may not be the most efficient solution.

In Addis Ababa, with Traffic Engineering perspective, new infrastructure measures did not prove to be adequate in that inefficiency is predominant. Thus, it was stated in this research to look on contributing factors that resulted in interruption of traffic flow conditions. Investigating, they are related to behavioral issues which are associated with Pedestrian Characteristics and Drivers' Behavior.

And as a methodology to conduct this research, a major highway corridor with representative traffic, pedestrian and driver characteristics was taken for investigation. Thus, the investigation was made via video recording of flow operations on six different locations for the three peak conditions (that is: AM Peak, Mid-Day Peak and PM Peak Periods) and attitude survey in a location where there is erratic pedestrian movement.

And after capturing the necessary data pointed out in the Study and Sample Size Determination Sections, the Analysis and Discussion Chapter revealed the findings as interpreted in **Section 6.2**. Thus, the researcher conclude that the findings are valid with the following limitations:

- ✚ Saturation flow rates couldn't be modeled for known demand flow rate values
- ✚ Crossing speeds and other impeding (perpendicular) and friction intriguing (parallel) movements of pedestrians is due to their response to local conditions. Thus, such results cannot be extrapolated to other areas without analogous comparisons

With the above two limitations only, the researcher of this paper recommends the findings to be replicable to other areas having the limitations in mind.

## **7.2. Recommendations and Future Researches**

In **recommending** the applicability of this research for adoption in practice and future research, the key findings summarized in bullets in **Section 7.1.** are justified statistically and the models derived are developed through the techniques in Strategic Modeling. Thus, the researcher of this study recommends them for applications here in Addis Ababa and other cities in developing countries with analogous characteristics. It is also evident to disclose that the findings can be used on most highways but not on everywhere.

And in pointing out research areas for **further researches** extrapolating from this unique research, the following facility types need attention.

- ✚ Signal Interrupted Facilities
- ✚ Two Way Two Lane Highways
- ✚ Incidents in Freeways, Expressways and Interchange elements
- ✚ Gravel Surfaced Roads
- ✚ Highways with severe pavement distresses and heavy gradients and
- ✚ Highways with segregated Bus Rapid Transit lines

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