SELECTION OF SUITABLE TRAFFIC MODEL USING FUNDAMENTAL DIAGRAM UNDER DIFFERENT ROAD GEOMETRY AND OPERATING CONDITION IN MEKELLE CITY SUB-ARTERIAL ROADS

MEKELLE UNIVERSTY

ETHIOPIAN INSTITUE TECHNOLOGY-MEKELLE (EIT-M)

SCHOOL OF GRADUATE STUDIES

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The thesis submitted to School civil engineering Mekelle University in partial fulfilment of the requirement for Masters of Science Degree in Civil Engineering (Road and Transport Engineering Stream)

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Declaration

I declare that this M.Sc. thesis titled "**SELECTION OF SUITABLE TRAFFIC MODEL USING FUNDAMENTAL DIAGRAMS UNDER DIFFERENT ROAD GEOMETRY AND OPERATING CONDITION IN MEKELLE CITY SUB-ARTERIAL ROADS** is my own work and, it has not been presented and other University for similar or any other degree award. Where material has been used from other sources it has been properly acknowledged and referred.

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ABSTRACT

The relationship between macroscopic traffic flow parameters (flow rate, speed, and density) is represented graphically by fundamental diagrams. These diagrams play an important role in traffic flow theory and transportation engineering. Most conventional traffic stream models are mainly applicable for homogenous traffic conditions. These models are not suitable for the traffic condition of Mekelle city which is characterized by weak lane discipline and heterogonous in nature. This thesis select suitable traffic model for different roadway geometry and operating condition. It also compares the flow parameters for the stated traffic condition.

For this thesis three different cases have been considered, those are road way with and without median structure, road way with and without footpath and road way with and without side market. Traffic data collection is done through video recording at midblock rod from six different locations. To select the suitable traffic model the speed –density plot of field data for different locations is fitted with five established FD models linear, polynomial 2nd degree, polynomial 3rd degree, exponential and logarithmic.

From the result, polynomial 3rd degree is the best FD model for case one which compares the roadway with and without a structural median. For the second case which comprises roadway with and without footpath, exponential models are the best-fitted model, but hence it doesn't satisfy the boundary condition to compare the flow parameters polynomial 2nd degree is the second best model. Similarly, for case three which compares roadway with and without side market the exponential and 3rd-degree polynomial is the best-fitted models, but hence exponential model doesn't satisfy the boundary condition to compare the flow parameters 2nd-degree polynomial is the second-best fitted model. It is also found that free-flow speed trends decrease if there is no structural median, footpath and if there is a road side activity by (4.8%, 6.19% and,9.11%). The jam density increases if there is no structural median, footpath and if there is a road side activity by (41%, 8.8% and, 6.68%) consecutively.

Key Words: Fundamental diagram, best-fitted model, heterogeneous traffic

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ABBREVIATIONS

CSA: Central Statistical Agency

FD: Fundamental Diagram

FHWA: Federal Highway Administration

GOF: goodness of fit

HCM: Highway Capacity Manual

LCV: Light Commercial Vehicle

MCRTO: Mekelle City Road and Transport Office

MUBECO: Mekelle University Business Enterprise and Consultancy Office

PCE: Passenger Car Equivalent

PCU: Passenger Car Unit

RMSE: Root mean square error

SMS: Space mean speed

CHAPTER 1

1. INTRODUCTION

1.1. Background of The study

Mekelle, the regional capital city of the Tigray region is located in northern Ethiopia highlands at 780 km north of the capital city Addis Ababa. As histories indicate Mekelle is originated as a settlement and as an urban centre in the second half of the 14th century by Emperor Yohannes IV. Mekelle is considered a special zone, which is divided into seven sub-cities. Mekelle city is one of the fast growing cities of Ethiopia and central economic hub of the region. The city has more than 2300 km network of road transport; of which 82 km is asphalt road excluding those under construction, 177 km is cobblestone road, and the rest 2083km classified under gravel and earthen road (Mekelle municipal office, 2018). Transport play vital role in the modern life style of a society. The fast and convenience movement of people and commodity from place to place has great impact in the economic development of individuals and nationwide. The economic development of entire region depend on the easy to access to people and goods ensured by existing transport technology. Due to its flexible and accessible nature road transport is one of the major transport mode, and different vehicles use this facility to facilitate the movement of people and goods. The contribution of cities in economic growth is high and movement in and between cities is crucial in day to day activity of the people and improved life style.

Traffic congestion is growing problem in Ethiopia. This congestion problem is high in large cities in the country like Mekelle. The economic activity of the city increase tremendously from time to time and there is rapid growing of population in number of the permanent settlers and people enter to the city from surrounding for different purposes. The city population increase 5% every year (CSA, 2013). The number of motorized vehicles increases from time to time Mekelle city. For period of 2011-2017 an average of 1883 passenger vehicles has been registered, even though road facility is unimproved, hence the road capacity is not matched with increasing demand of traffic. This conditions show there is a need for correct solution to balance the traffic demand and the road facility for proper management of traffic congestion and reduce its effect.

The proper planning, design, implementation, and operation of road infrastructure need knowledge of flow characteristics and flow parameters. Planning of road infrastructure must be done by considering the present and future traffic state. Otherwise, after few years of construction, the capacity of the road will be exceeded and will need further widening, in this case, the primary requirement is to know the appropriate traffic flow characteristic and accurate flow parameters. The relationship between flow, speed, and density called fundamental diagram to play a very important role in traffic flow theory and traffic Engineering. For example, the speed-flow relationship can be used in high way capacity analysis to determine the highway service quality, and the speed-density relationship can reflect the dynamic change in traffic flow, which can be used to study the disturbance propagation between vehicles. Therefore, the sound mathematical model provides a solid foundation for traffic flow analysis and efficient traffic management. To investigate the traffic flow characteristic, finding out FD is one of the most important requirements. The FD (describing flow-density, speed-density or speed-flow relationship at a given location or section of roadway) is a basic tool in understanding the behaviour of traffic stream characteristics in macroscopic flow models. It can be used to predict the capacity of the road, or its behaviour when applying inflow regulation or speed limit. In the nominal work of Greenshield (1935), FD was defined and used as the relationship between flow rate (q) and density (ρ) for an equilibrium traffic state. Since then, several works have been conducted to establish a static relationship between q and ρ in theory and empirical modelling with field data fitting. It is generally recognized that FD is location-dependent due to road geometry and traffic characteristic. Greenshield postulated a linear relationship between speed and traffic density. When using the relation Flow=density*speed; the linear speed-density relation converts into parabolic relation between speed and traffic flow. The term flow is not known at that time and Greenshield called that term 'density-vehicle per hour' or density of the second kind. Many models exist for modelling the static ν-ρ model and q-ρ relationship. Although the function expressions are different; they are more or less similar in the domain $\rho\varepsilon[0, \rho j]$.However some of them don’t satisfy the boundary condition $\nu(0) = \nu_f$, $\rho=0$ simultaneously. Few well-known models for speed-density relationship are logarthmatric Greenberg Model(1959), Edie Model (1961), Polynomial Model (Zhang,1999) and Exponential Model by Papagergiou (2002) and Hegyi (2002).Edie Model was a combination of Greenberg Model and Underwood (1961).This combination removed some shortcomings such as violation of the boundary condition of those two models.

The most recent works of traffic modelling focused for homogeneous traffic. Heterogonous traffic mixes are the common site of appearances in all the developing economies and cities including Mekelle city, the traffic operating condition is non-lane based and highly heterogonous. Although non-motorized vehicles have been banned from major high ways in Mekelle city recently, the fact remains that the traffic comprises of a private car, mini-bus, truck, covered van, auto-rickshaws (Bajaj) and other utility vehicles of varying shape, size, speed, and other operating conditions. Highway capacity is greatly affected by widely varying physical and dynamical characteristics of vehicles in addition to the absence of lane discipline. There is a significant difference between the behaviour of homogeneous and heterogonous traffic streams. Thus, it is necessities modelling fundamental diagrams with empirical data of heterogonous traffic under different road geometry and operating conditions for Mekelle city.

1.2. Statement of Problem

Traffic congestion is a current problem in all cities of Ethiopia. Even though the vehicle ownership rate is lower in comparison to developing countries, the congestion problem is high and this is the main cause for traffic accident and air pollution. It is also common to see congested roads mainly at peak hours in Mekelle city nowadays; this condition hinders the smooth traffic flow and negatively affects the economic growth of the city. The number of vehicles in Mekelle city increasing from time to time by an annual average growth rate of 17.34%, vehicle data found on transport office for the last six years showed that an average of 1835 vehicles per year has been registered (MCRTO, 2017).The proportion of motorized vehicles from traffic count for all trips is 51.63% previous study (in 2010) show the same proportion were accounting 67.24%. Hence the current result show there is an increase in motorized transport in the city (MUBECO, 2014).

As stated by the community during information gathering from road users the inhabitants suffer from narrow width of roads that are mismatched with the traffic demand (MUBEO, 2014). The geometric features of the existing roads deviated from standard levels; because of this reason streets in Mekelle city are serving without footpath, structural median and bicyclist facility.

1.3. Research Questions

The major research questions are follows

- What kind of fundamental diagram (trends) and model is found for heterogonous traffic flow of the main roads on the city?
- Which kind of mathematical model is best fitted model from five mathematical models and suitable for modelling the traffic flow in the main roads?
- How can different geometric features of road and operating condition affect the flow parameters and flow condition?

1.4. Research Objectives and Scope of Study

The overall objective of this research is to investigate the impact of road geometry and traffic operating condition on traffic flow parameters. However, the specific objectives are:

- Finding the shape and structure of fundamental diagrams for different road geometry and operating condition
- Finding the best fitted FD model using data from the existing geometric condition and operating condition
- Finding the trend in flow parameters for different road geometry and operating condition

It is expected that the obtained flow parameter value for different road geometry and traffic operating condition will provide a guideline to estimate the capacity of the road for the best geometric design. It is also expected this research will lead to a development macroscopic traffic flow model suitable for non-lane based heterogeneous traffic. With these models, it will be possible for designing different proactive flow control strategies. For this study, three different geometric and traffic conditions will be considered. These are listed below

Case 1: Roadway with median structure and without median structure

Case 2: Roadway with footpath and without a footpath

Case 3: Roadway with road side activity and without road side activity (market)

1.5. Limitation of the Research

Due to different reasons it was challenging to collect traffic data for consecutive seven days to get accurate traffic volume but the researcher take only one day traffic volume after collecting three days count. In addition to this we select three main roads for two different geometric conditions and operating conditions.

1.6. Significance of the research

This research is generating fundamental diagrams and traffic flow models between basic parameters for heterogonous traffic flow. These models are vital in planning and operation of existing road. So, this research is significant for both researchers and city transport administers to develop different proactive flow control strategies and to improve the geometric feature and operating condition of road for smooth traffic flow.

1.7. Organization of the Thesis

This thesis consisting of five chapters and annexes is organized as follows:

Chapter 1 gives an introduction of the relevant research background, statement of the problems as well as the objective and scope of the studies.

Chapter 2 comprehensively reviews the basic relationship between traffic flow parameters and previous works on modelling FD with a special focus on the speed density model. Few conventional and modified models are reviewed in detail. During this review special emphasis is given on modelling FD for heterogonous traffic flow conditions.

Chapter 3 present detail of the study area selected and empirical traffic data collection and sampling technique for this research. Some justification regarding the choice of methods and choice of study area employed are also provided.

Chapter 4 present the development of FD models for 3 different cases of different road geometry conditions and operating conditions for non-lane based heterogonous traffic in Mekelle city. The shape and structure of the best-fitted model will be investigated for all cases. It will also be investigated how the flow parameters e.g. the free-flow speed and jam density change with a change of road geometry.

Chapter 5 summarizes the main conclusion of this research and discusses recommendations for future research work related to FD modelling for heterogonous traffic.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

Traffic stream flow is described by three basic variables: the mean speed (v), traffic density (ρ) and traffic flow rate (q). The functional relationship between these three parameters is called a fundamental diagram. It gives the relation between speed-flow-density at equilibrium condition. Generally, there are three types of FD used to represent the basic relationship between speed, density, and flow. These are a speed-density relationship, speed-flow relationship, and flow density relationship. The three diagrams shown in figure 2.1 have a particular use and purpose. Speed-density diagram is used to formulate the car-following model; it is the interactions between vehicles in the traffic stream were speed is a function of space. Flow- density diagram is used as the bases of freeway control system were density (percent occupancy) is used as a control parameter and flow (productivity) is an objective function. Finally, the speed flow diagram is used to determine the level of service of the roadway. However, in this thesis, more emphasis is given on the speed-density FD. So, the review focuses on speed-density models

2.2. Traffic Flow Basic Parameters and Their Relationship

Parameters used to describe the traffic stream could be categorized as microscopic and macroscopic. The microscopic model is considering the behaviour of individual vehicles in traffic streams for each other example spacing, headway. The macroscopic model is considering the traffic stream as the whole example density, speed, and flow. The relationships between fundamental variables of traffic flow present graphically in figure 2.1 were a liner speed-density relationship is selected for this case to show the interaction between speed and density. This relationship indicates that speed approaches free-flow speed (ν_f) when density and flow approach zero ($\rho \to 0$ and $p \to 0$). As density and flow increase speed is reduced until the flow is maximum (q_m), speed and density approach their optimum value ($\nu \to n_0$ and $\rho \to \rho_o$). Further, an increase in density results in lower speed and lower flows until density reaches its maximum value the jam density condition (ρ_j) and correspondingly speed and flow approaches to zero($\nu \to 0$ and $q \to 0$). The flow rate curve touch the speed density curve at a point when the flow is maximum (q_m) and at an optimum value of speed and density (ν_o and ρ_o)

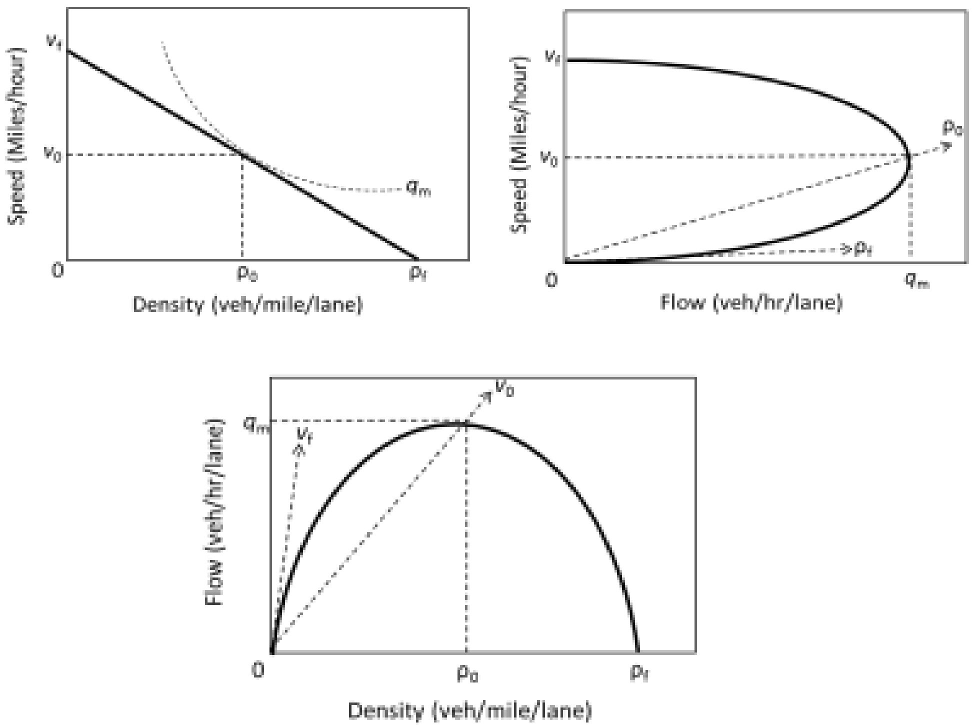

Figure 2. 1 Fundamental Diagrams

The flow-speed relationship is shown in figure 2.1 b, under very low flow condition ($\rho \to 0$), flow approaches zero ($q \to 0$), and speed approaches free-flow speed ($\nu \to \nu_f$). As flow increases, density increases while speed is decreasing. When optimum density reached, the flow becomes maximize. Further increase in density results in the decreased flow until finally, as jam density is reached and flow approaches to zero. The spaces mean speed represented by a radial line from the origin of the curve up to the flow density curve. The stepper slope indicates maximum speed while horizontal speed represents a speed of zero. The slope of a flow density curve is the space mean speed for maximum flow. The speed-flow relation is shown in figure 2.1 c has two regimes the upper regime and the lower regime. The upper regime is under a saturated (free flow) regime and the lower regime is saturated (congested) flow regime. Under the free-flow condition, speed decreases as flow level increase up to maximum flow. The saturated (congested) flow regime flow conditions with flow rate reduced below capacity which is associated with further reduced speed. At this condition, the density exceeds optimum density.

2.3. The Fundamental diagram Models

The first traffic flow studies on a highway is derived from Greenshield observations in 1930, he carried out tests to measure traffic flow, traffic density and speed using photographic measurement methods for the first time. Greenshield postulated a linear relationship between speed and density (Greenshield, 1935). There have been additional efforts to improve the linear relationship between speed and density. These efforts include Greenberg's model (Greenberg, 1959), the model uses fluid flow analogy and data from the Lincoln Tunnel in New York to establish a logarithmic relation between speed and density. In addition to Greenberg model the Underwood model (Underwood, 1961), Drake model (Drake, 1961), Northwestern (Drake & May, 1967; Drew, 1968), Pipes Munjal Generalized model (Pipes, 1967), Modified Greenberg model (Ardekani & Ghandehari, 2008), Van Aerde Model (Van Aerde, 1995) and Mac Nicolas model (Mac Nicolas, 2008).From the enormous works in fundamental diagrams, many models exist to model speed and density at equilibrium. Although the function expressions are different they are similar in the domain. However, some of them don't satisfy the boundary condition. Some of the conventional and modified models are discussed below.

2.3.1 Conventional Fundamental Diagram Models

Greenshields Model

The model was proposed by Greenshields in 1935 as a linear model to analyse the relationship between speed, flow, and density. The model is simple and satisfies all boundary conditions, (u=0 at ρ=ρj and ν=νf at ρ=0, the Greenshield formulation is as follows.

$$v = vf\left(1 - \frac{\rho}{\rho j}\right) \quad (2.1)$$

Where v *is* the speed, ρ-density, v_f-free-flow speed and ρ_j-jam density.

Greenberg Model

Proposed by Greenberg in 1959, the model uses fluid flow analogy and data from Lincoln tunnel in New York to establish a logarithmic relation between speed and density, namely

$$v = v_c \ln \frac{\rho}{\rho j} \quad (2.2)$$

Where v_c is the speed at capacity.

The model does not satisfy the boundary condition at the low concentration regime ($v \rightarrow \infty$ at $k=0$) but behaves well under congested conditions ($v=0$ at $\rho=\rho j$)

Underwood Model

Developed by Underwood in 1961, the models hypostasize an exponential relationship between density and speed. The model is observed to generally have a better fit than Greenshield and Greenberg model for the uncongested traffic condition, but does not present a good fit to the data for congested condition .the Underwood model is given as

$$v = v_f e^{-\rho/\rho c} \tag{2.3}$$

Were ρ_c is density at capacity

Drake Model

This model was developed by drake in 1961. He studied macroscopic traffic models postulated at the time and he does not find any of them is significant. In developing his model, he estimated the density from speed and flow data, fitted the speed vs. density function and transformed the speed vs. density to speed vs. flow function. His model generally yields a better fit than the above three models for uncongested condition, however, as in Underwood case, it is not a good fit for the congested condition. The formulation of the Drake model is as follows

$$v = v_f exp[-\frac{1}{2(\frac{\rho}{\rho_c})^2}] \tag{2.4}$$

2.3.2. Modified Fundamental diagram Models

There are many combinations and modifications of the conventional models which are known as modified (non-classic) models are discussed below.

Edie Model: It is a combination of Greenberg and the Underwood model. This combination removed some shortcomings such as the boundary condition of those two models. Edie model is expressed as:

$$v(\rho) = \begin{cases} e^{\left(-w1\frac{\rho}{\rho j}+w2\right)}, \rho \leq \rho j \\ g1 + g2 \ln\left(\frac{\rho}{\rho j}\right), \rho > \rho j \end{cases} \tag{2.5}$$

The Modified Greenberg Model: Considering under light traffic condition there are always some vehicles on the freeway, the modified Greenberg model introduces a non-zero average minimum density, ρ_o in the Greenberg model (Ardekani & Ghandehari, 2008).The Modified Greenberg formulation is

$$q = v_c \rho \ln \frac{\rho o + \rho j}{\rho + \rho o} \tag{2.6}$$

Where ρ_o is the average minimum density, v_c speed at capacity

Unlike the conventional Greenberg model, the modified version yields a finite free-flow speed that yields a finite free-flow speed of $v_f = v_c \ln(1+\rho/\rho_j)$ when the density approaches zero.

The Underwood Model with Taylor series Expansion: the Underwood model doesn't yield the solution for jam density when speed approaches zero. But the exponential function can be expanded in a Taylor series obtaining a numerical approximation for jam density.

$$v = v_f e^{\frac{-\rho}{\rho c}} = v_f \left(1 - \frac{\rho}{\rho c} + \frac{\rho^2}{2\rho c^2} - \frac{\rho^3}{6\rho c^3} + \frac{\rho^4}{24\rho^4} - \frac{\rho^5}{120\rho^5} + \cdots\right) \tag{2.7}$$

Taking up the term containing ρ^3 yields

$$v = v_f e^{\frac{-\rho}{\rho c}} = v_f \left(1 - \frac{\rho}{\rho c} + \frac{\rho^2}{2\rho c^2} - \frac{\rho^3}{6\rho c^3}\right) \tag{2.8}$$

For u=0, the solution of eq. (2.8) gives an estimate of jam density,

The Polynomial and Quadratic Models: we can also express the relationship between density and speed in terms of the second-degree polynomial.

$$v = v_f + b\rho + c\rho^2 \tag{2.9}$$

b and *c* are additional model parameters.

Alternatively, the speed vs. density relationship may be expressed as a quadratic equation of the form

$$v = v_f \left(1 - \frac{\rho^2}{\rho j^2}\right) \tag{2.10}$$

The Drake Model with Taylor Series Expansion: as in the case of Underwood, the Drake model doesn't yield the solution for jam density when speed approaches zero. Hence we can use the Taylor series expansion to obtain a numerical approximation for jam density, as follows

$$v = v_f \left(1 - \frac{\rho^2}{2\rho c^2} + \frac{\rho^4}{8\rho^4} - \frac{\rho^6}{48\rho^5}\right) \tag{2.11}$$

At *u*=0 the solution of the equation would yield an estimate of jam density, ρ_j

The polynomial and quadratic models: we can also express the relationship between density and speed in terms of the second-degree polynomial equation.

$$v = v_f + b\rho + c\rho^2 \tag{2.12}$$

Where b and c are additional model parameters

Alternatively, the speed vs. density relationship may be expressed as a quadratic equation of the form

$$v = v_f \left\{1 - \frac{\rho^2}{\rho j^2}\right\} \tag{2.13}$$

The following polynomial model is cited in (Zhang, 1999) as the one-parameter polynomial model:

$$v = v_f \left(1 - \left(\frac{\rho}{\rho c}\right)^n\right) \tag{2.14}$$

Exponential Model: An exponential model used by Papageorgiou et al. (2010) and Heygi et al. (2002)

$$v(\rho) = v_f exp\left(\frac{-1}{a}\left(\frac{\rho}{\rho c}\right)^a\right) \tag{2.15}$$

Were v_f is free-flow speed, a model parameter, ρ_c critical density. It resembles somehow to Underwood exponential model.

Complex Model: A complex model used by Newell (1961) and Del Castillo (1995)

$$v = v_f \left\{1 - exp\left[\frac{-\lambda}{v_f}\right]\left(\frac{1}{\rho} - \frac{1}{\rho_j}\right)\right\}\Bigg] \tag{2.16}$$

Here $\frac{-\lambda}{v_f}$ represents the Cj i.e. the kinematic wave speed in Del Castillo and Bentiz (1995) model; therefore $\lambda = c_j\rho_j$ and the value depend on kinematic wave speed and the jam density.

Complex models cited from (Wang et al, 2010) and (Lee et al, 1998) were presented below

$$v = v_c + \frac{v_f - v_c}{\left[1 + exp\left(\frac{\rho - \rho c}{\theta 1}\right)\right]^{\theta 2}} \tag{2.17}$$

2.4 speed-density FD Model

Vital road network characteristics like free flow speed; critical speed and jam density are obtained from speed density model. Studies indicate that the relationship between speed and density are primary entity for traffic flow model (van Maarseven,Zudigeest et al. 2005). The relationship between these two parameters provides essential information for planning purpose. Daganzo and Gerolimins develop speed density model through the combination of measurement from 500 fixed sensors at Yokhoma city in Japan with large data sample derived from GPS devices in taxi

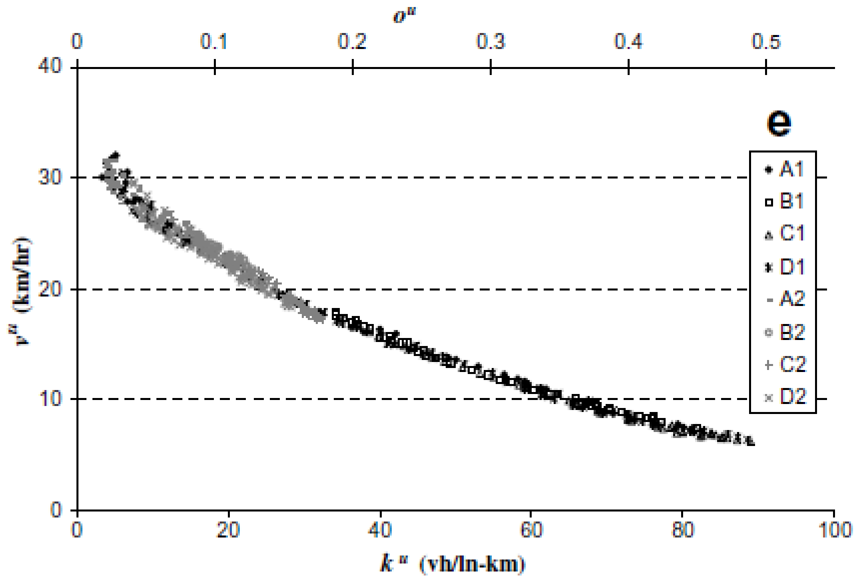

Figure 2. 2 Speed Density Relation for City Of Yokohama, Japan

Source (Daganzo and Geroliminis, 2008)

The graph show that when single road user uses the road way he could derive at any desirable speed because density(k) is low and this is free flow speed(u_0) since the choice of speed is not limited by other road users. When more and more drivers begin use the road way, density increase and speed decrease significantly (because of the many interaction among vehicles) till the road capacity reached. When the product of speed and density result in maximum flow, the capacity is reached and this referred to as optimum speed u_c (often called critical speed), (HCM, 2010).At a point in time, density become so high such that all vehicles stop and speed is now zero (this condition is the jam density, k_j).Information such as this from the diagram is essential for planning, traffic management and safety purposes to improve the accessibility. This can be done with pricing, rationing and perimeter control strategies based on neighborhood accumulation and speed (Daganzo and Geroliminis, 2008).Knowledge about the cities jam density helps to put in place effective measures to control traffic flow in the city so that the city's flow do not get to such high levels.

2.5. Comparison FD models for heterogeneous and homogenous traffic flow

The traffic composition in developing and developed country is fundamentally different .The traffic in developed country is predominantly composed of passenger cars and this term can expressed as homogeneous traffic. Unlike the developed world the traffic composition in developing world is widely varied in static and dynamic characteristic, which occupy the same right of way, resulting in non-lane based discipline termed as heterogeneous traffic flow condition. From previous studies, it found that homogenous networks have well defined FD models, while heterogeneous road networks have not well defined FD. A review of the literature has shown that most of the studies in such traffic make use of the methods and concepts developed for homogeneous traffic. Very few researches have attempted for mixed traffic. R.S.Dhapdukar (2014) studied fundamental diagrams in different categories of highway in India and develop a linear speed density relationship by regression analysis as shown in figure 2.2.

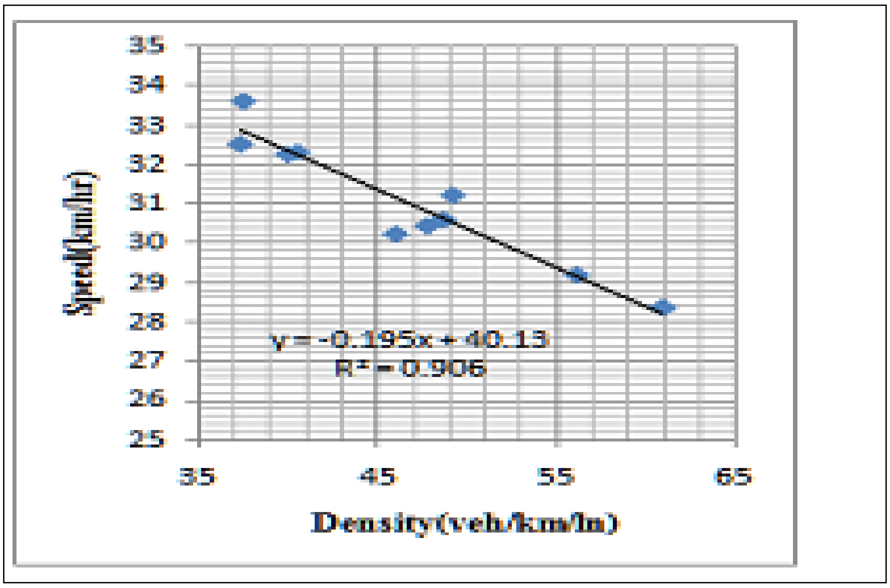

Figure 2. 3 Linear Speed Density by R.S.Dhapkudar (2014)

H.Krishna and K. Ramachandra (2018) studied to fit and evaluate speed-density functional forms for heterogeneous non lane based traffic in urban arterials of India. Approximately 12 hours of data were collected at Panchsheel Marg and Ho-chi-Minih arterial roads located in Delhi India. Video image processing software was used to extract individual vehicular speed and classified volume (flow) .The Wang et al. (2010) complex traffic stream model was found the best fit model for speed-density relationship in terms of R and RMSE values as shown in figure 2.3.

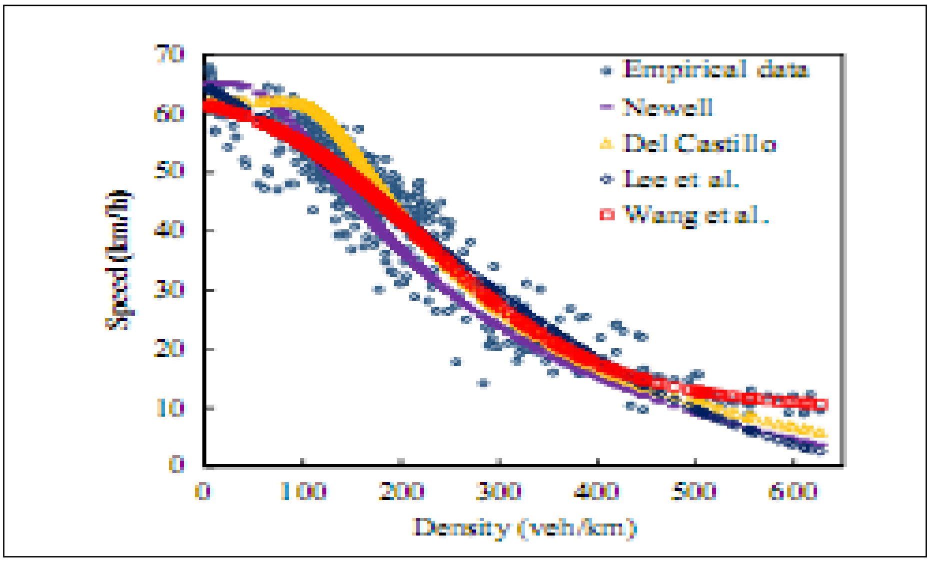

Figure 2. 4 Fitness of Complex Stream Model by H.Kirshan and K.Ramachndra (2018)

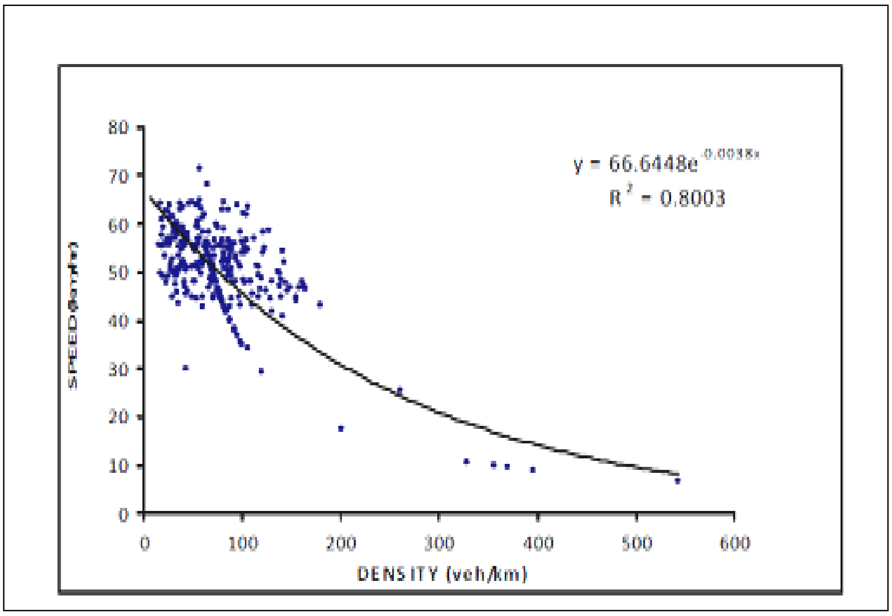

Figure 2. 5 Exponential FD by Thankappan et al. (2010)

Generally, this chapter provides inspection of the relationship of basic parameters in traffic flow and modelling fundamental diagrams to describe the speed-density relationship of traffic flow. Recent studies reviled that most of the models exist in developed countries with homogenous and lane-based conditions. But for this case, the traffic is mostly non- lane-based heterogeneous for which standard FD models have not developed.

CHAPTER 3

3. RESERCH METHDOLOGY

3.1. Introduction

These portions of the research explain and justify the selected study area, traffic data collection and sampling method, data analysis methodology adopted for the research. The collected data will serve as an input to develop the fundamental models to represent speed-density relationship at different road geometry and traffic operating condition.

3.2. Description of the study area

For this thesis, three cases for different road geometric and traffic operating condition are considered. For these cases, three different main roads are considered as study area. For case-1 the road from Hawzen Roundabout to Hawelti signalized intersection was selected as study area. It is a 2-lane road (1-lane each direction) without median structure up to Adi-Haki bridge entry and with median structure up to Hawelti signalized intersection. The average carriage way width of the road is 7m (3.5m each lane).It is among the busiest roads of the city which connects west part of the city with the centre; with relatively good pavement condition and it entertains high motorized traffic. The traffic stream at the study site consists of minibuses, auto-rickshaws, cars, pickups, motorcycles and utility vehicles. Lane discipline is absent all through, because of such geometric and traffic characteristic the test site selected as a study location for the non-lane-based heterogonous condition. The study route selected for the second case is the road from Alula Abanega AirPort to Quiha town. This road is classified under the main national highway road (Trunk road) that extended to the capital city Addis Ababa and pass through Quiha sub-city. The carriageway of this road is good asphalt pavement with average width of 14 m(7.5m each lane), and the road has not proper footpath from Airport roundabout up to the junction of the road direct to St.Cherkos Church and has 2m average width proper footpath up to Quiha roundabout. This road is functionally very important to connect Mekelle city with neighbours' cities and the capital city and it entertains with a different class of vehicles such as minibus, auto rickshaws, trucks, cross country heavy utility vehicles and buss.

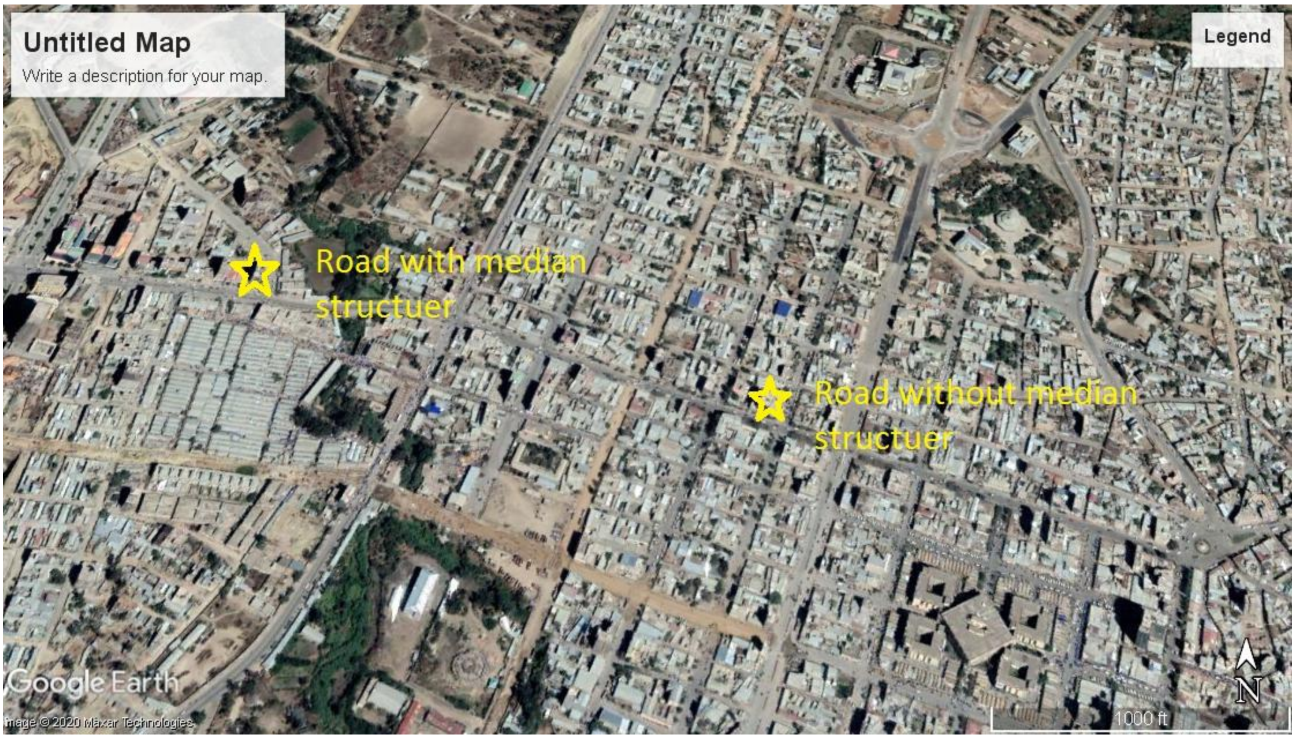

Figure 3. 1 Satellite Image of Hawzen Roundabout to Hawelti Signalized Intersection Road

Figure 3. 2 Satellite Image of Alula Abanega Airport to Quiha Sub-City Road

The study route selected for the third case started from Encodo primary school around St. Rufael church, which intersects the main road from Hawzen Roundabout to Hawelti intersection. This road passes through the Adi-Haki market to the compound of martyr's memorial monument. It is a 2-lane road (1-lane in each direction).The average width of the road is 7m (3.5m each lane). There is a road side activity (market) between the un-signalized intersection and the way to martyr's memorial monument. It is a street market for vegetables, clothes and other commodities as an extension from the big marketplace Adi-Haki adjoining the road. There is a big crowd on the roadside due to the presence of the market; the traffic stream at this site consists mainly of minibuses, auto-rickshaws and cars. Lane discipline is also absent in the third study area, because of such geometric and traffic characteristic the test site selected as a study location for the non-lane-based heterogonous condition.

Figure 3. 3 Satelite Image of Encodo primary School-Martyr’s Monument Compound Road

3.3. Data Collection and Sampling Technique

3.3.1 Data Collection

The collection of empirical traffic data required for fundamental diagram modelling is a very challenging task under the existing traffic condition of the study area. Generally, there are two methods to collect traffic data manual and automatic. Manual counting involves one or more persons recording observed vehicles using a counter. The main disadvantage of manual count methods is that it is labour-intensive (expensive), it subjects with limitation of human factors and it cannot use for a long period of counting. Automatic traffic data counting technology is classified into two categories: intrusive and non- intrusive methods.

The intrusive methods are automatic traffic data collection technologies that consists surface detectors (such as pneumatic road tubes) or subsurface detectors (non- invasive such as magnetic or electric contact devices) on the road and detect the passing vehicle and transmit the information to the controller which is connected to the detector at the side of the road. Some important intrusive methods are pneumatic road tubes, piezoelectric sensors, and magnetic loops. Pneumatic road tubes are rubber tubes placed across the road lanes to detect vehicles from pressure changes that are produced when vehicle tire passes over the tube. The main drawback of this technology is it has limited lane coverage and its efficiency is subject to weather, temperature and traffic conditions. This system may also not efficient in measuring low-speed flows. Piezoelectric sensors are placed in a groove along the roadway surface of the lanes monitored. The principle is to convert mechanical energy into electrical energy. The mechanical deformation of piezoelectric material modifies the surface charge density of the material so that potential difference appears between the electrodes. The amplitude and frequency of the signal are directly proportional to the degree of deformation. This system can be used to measure weight and speed. Magnetic loops are the most common methods to collect traffic data. The loops are embedded inroads way in a square formation that generates a magnetic field. The information is then transmitted to a counting device placed on side of the road. The drawback of this method is the technology has short life expectancy because it can damage by heavy vehicles and high maintenance cost to fix. The strong side of this method is it is low venerable to bad weather conditions. This technology is highly adapted in Europe. Non- intrusive technologies include video data collection, passive or active infrared detectors, microwave radar detectors, ultrasonic detectors, passive acoustic detectors, video image processing, and aerial photography. The manual count is the most traditional method but it is ineffective for non-lane-based heterogeneous traffic conditions. Other methods are very expensive, affected by weather conditions and also not effective for heterogeneous traffic conditions except video data collection. Video cameras can record vehicle number, type, and speed very easily. This is an efficient and cost-effective method of empirical traffic data collection in heterogonous traffic conditions. So this method is adopted for this study.

3.3.1.1 Traffic Volume Data

Traffic volume studies are conducted to determine the number and classification of road way vehicles at given location. Previous studies of traffic count by municipal was conducted for seven days in the major traffic counting stations and the result show that heavy traffic was recorded on Monday (MUBEO,20140).hence, the traffic volume for this study for all cases conducted on Monday. The peak hour also traced from previous study; 7:00-9:00 AM and 4:30-6:30 PM was peak hour for morning and evening period respectively. First video was recorded, and then converted to computer the number and type of vehicle was extracted from video at 5 minuet interval. The vehicle was counted in category as car, Motor bike, Minibus, Medium bus, large bus, Pick-up, LCV, Autorikshew (Bajaj), Heavy truck, Truck trailer. Directional design hour volume (DDHV) is a one way volume in two-way road facility in the predominant direction of travel .for rural and sub urban roads the directional distribution factor range from 55-80%, distribution factor of 50% used for urban roads (FHWA,2018) . For this research directional distribution factor of 50% used, the dominant lane in the morning peak is a lane with traffic volume heading into central business district and the dominant lane in the evening is a lane with traffic volume outbound from central business district. The location of video camera for data collection for three different cases shown at Figure 3.4, 3.5 and 3.6.

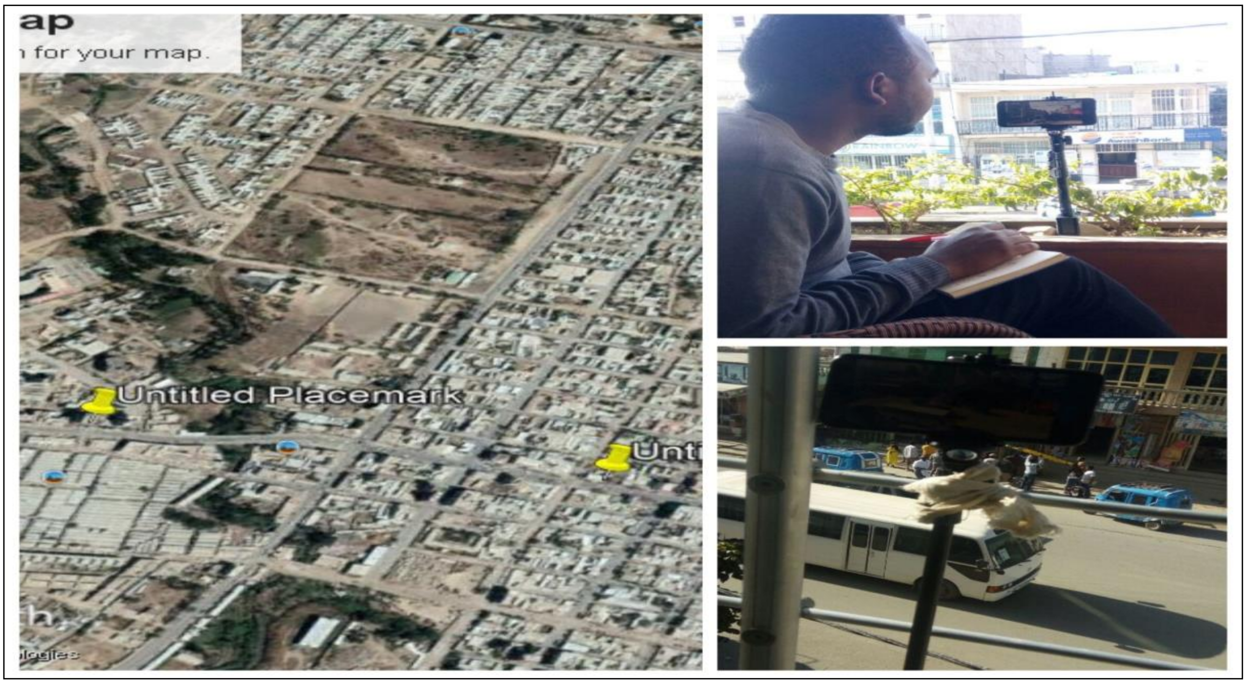

Figure 3. 4 Video Recording at Study Site Hawzen Roundabout to Hawelti Signalized Intersection Road

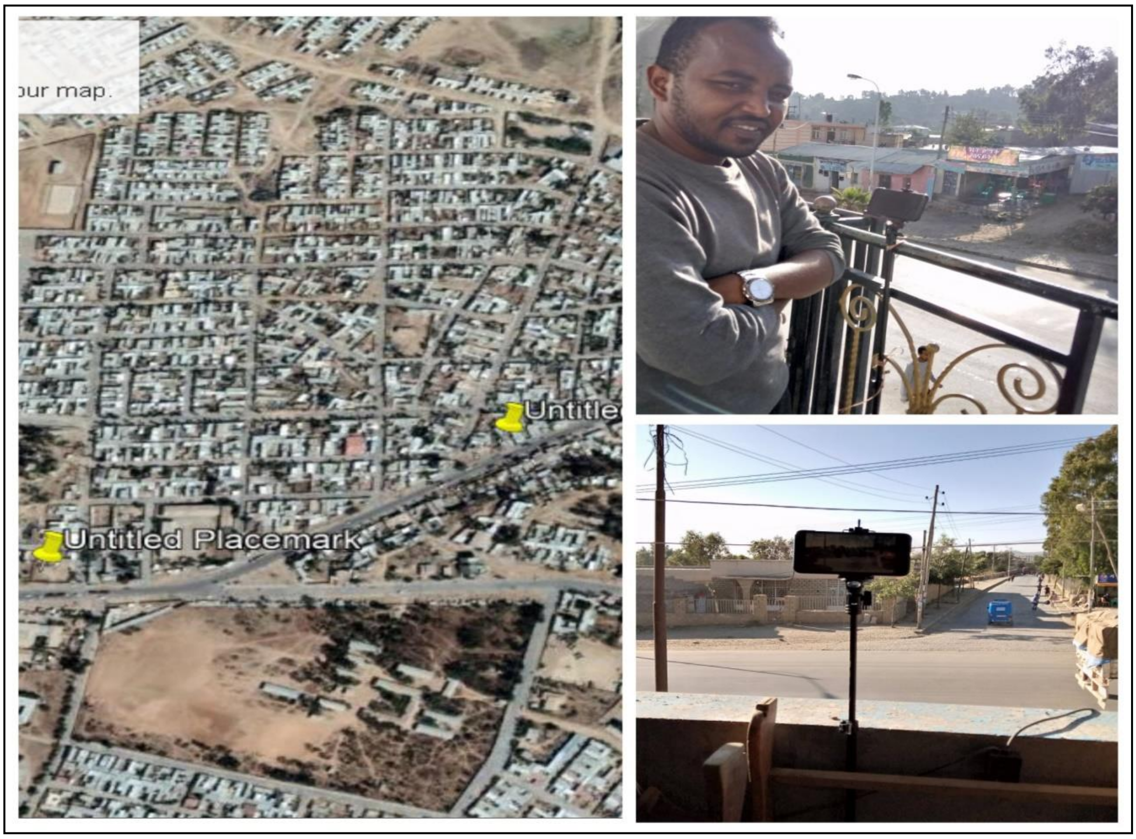

Figure 3. 5 Video Recording at Study Site Alula Abanega Airport to Quiha Sub-City Road

Figure 3. 6 Video Recording at Study Site Encodo primary School-Martyr's Monument Compound Road

3.3.1.2 Travel Time Data

Speed is an important transportation consideration because road users relate speed to economics, safety, time and convenience. Speed is fundamental measurement of traffic performance on the road system. Speed of the vehicle is defined as the rate movement of the vehicle in distance per unit time; it is usually expressed as in kilometre per hour (km/hr.) or mile per hour (mi/hr.). Spot speed is the instantaneous measures of speed at instantaneous measure of speed at specific location. The mean value of speed of individual vehicles can be determined either as time mean speed or space mean speed. Time mean speed is the arithmetic mean of individual speeds and space mean speed is the harmonic mean of individual speed (HCM, 2000).The technique that has been adopted to calculate the space mean speed data in this thesis was traced from manuals and recent works to conduct spot speed study by manual method. This method is applied in midblock nearly straight road by measuring the travel time of vehicles in second to transverse two reference points with known distance. Travel time is composed of running time, or time on which the mode of transport is in motion and stopped delay, or time in which the mode of transport stopped. For this research total six peoples participated in travel time data collection, prior to the field work the team introduced about the general procedures of travel time data collection and to conduct the work without giving conscious reminder to the drivers in the road. The total six peoples in team divided in two groups each team with three members for two different cases in 3 different study areas. The general procedure is the same for all study areas, one person stand at the entry of the first reference point and the second person stand at the exit of the second reference point. The third person in the team is stand at the position which is visible for the two persons to control the signs of the flag in their hand to record the total time lapse in second to transverse the distance by the study vehicle. For case 1 the distance marked for a roadway with a separated median is 25m and for roadway without separated median is 30m. For case 2 the distance taken for a roadway with footpath is 25m and roadway without footpath is 30m. Similarly, the distance marked for case-3 the distance marked to measure the travel time in second for road way with road side activity is 23m and for road way without road side activity is 27m. This measurement is conducted directional at 5 minute simultaneously with traffic volume data collection process for consecutive morning and evening peak hours. After the travel time data recorded for the sample of vehicles in the study area the data is tabulated in excel sheet and calculate space mean speed for each time interval by formula given below

$$v_{SMS} = \frac{n*d}{\sum ti} \qquad (3.1)$$

When d = distance travel

n = number of observation

t_i = travel time of i'th vehicle

3.3.2 Sample size estimation

Sample size estimation is fundamental to traffic engineering analysis. There are several sample size estimation methods which avoid using iterative procedures, such methods are merely approximations of the fundamental sample size estimation methods which uses standard deviation and t-statistic (Nazmuddin et al, 2000). Manual of traffic engineering studies and the manual of transportation engineering studies use standard devotion to calculate sample size for spot speed studies. In this thesis the sample size estimation technique is adopted from recent works and manuals. The sample size estimation is manipulated using the standard deviation; required sample size is calculated for desired accuracy at given confidence level if the calculated sample is less than the initial number of data point the data taken initially is enough to estimate the population mean.

The minimum sample size required to estimate a variable with an accuracy of ±ε unit at a certain confidence level is given by the formula

$$n = \left(\frac{t * s}{\varepsilon}\right)^2 \quad (3.2)$$

When

S= sample standard deviation

t= student *t*-statistics for given confidence level in this thesis it is 95%

If the variable is normally distributed initial number of sample ≥ 30 is available to calculate the standard deviation the value of ε recommended 2, 3 and 4 for confidence level of 90%, 95% and 99% respectively.in this thesis an average of 2.5 is taken for sample size estimation.

3.4. Analysis Methodology

The analysis of traffic flow and space mean speed data is manipulated using Microsoft excel software (2010 version), and the data analysis packages apply to develop the model and to compare the best fitted fundamental diagram model using R^2 and RMSE. ANOVA test package used to manipulate the hypothesis test and for model validation.

CHAPTER 4

4. RESULT, AND DISCUSSION

4.1 Introduction

Fundamental diagram is a basic tool in understanding the behaviour of traffic stream characteristics in both macroscopic and microscopic traffic flow models. To investigate traffic flow parameters finding the shape and structure of FD is one of the most important requirements. FD gives a functional relationship between three basic parameters (speed, density, and flow rate) of traffic flow for an equilibrium state. However, the speed-density relationship is the main focus of this research. This chapter presents the development of FD models for different road geometry for non- lane-based heterogonous traffic of Mekelle city. Then the shape and structure of the best-fitted model will be investigated for all the cases. Finally, it will also investigate how the flow parameters e.g. the free-flow speed and jam-density change with the change of road geometry and traffic operating conditions.

4.2 Analysis to Develop the Model

4.2.1 Normality Test and Constructing Confidence Intervals

The number of most common statistical test relies on normality of sample or population.it is useful to test whether the underlying distribution is normal. There are different techniques to test the normality of a given data distribution in this research the Q-Q(quintile-quintile plot) applied to test the normality of space mean speed data distribution which was calculated using travel time data from the field measurement. The Q-Q (quintile-quintile plot) is a scatter diagram between ranges R_1 consisting of element $x_{1,.........,}x_n$ in ascending order and R_2 consisting of values NORM.INV(1/2n,x,s),............, NORM.INV(1-1/2n,x,s),where x=AVERAGE(R_1) and s=STDEV(R_1).For sample of space mean speed data distribution for different the three study areas and six different geometric and operating condition variations, the Q-Q(quantile-quantile) plot for space mean speed distribution was suited on the leaner line this shows the data is approximately normal distribution.in addition to Q-Q plot frequency distribution of the space mean speed a symmetric bell shaped graph showed the normality of the data. After normality of the speed distribution is checked the next step is to construct the confidence interval for a given sample speed distribution. When the μpopulation variance is unknown and the sample is normally distributed a (1-α) 100% confidence interval for population mean (μ) is

$$\mu = \overline{x} \pm t\alpha/_2 \frac{s}{\sqrt{n}} \qquad 4.1$$

Where s is estimated square root of variance and n is random sample of speed from the population and $t\alpha/_2$ is the value of *t*-distribution with n-1 degree of freedom (showed Appendix IV) using a 95% confidence interval and 5% significant level we calculate and set the upper and lower confidence limits for population mean of space mean speed for three different cases in the research are presented below

Case 1: $\overline{x} \pm t\alpha/_2 \frac{s}{\sqrt{n}}$ = 23.67 ± 1.96 * 6.99/$\sqrt{2880}$ = [23.41, 23.93]

Case 2: $\overline{x} \pm t\alpha/_2 \frac{s}{\sqrt{n}}$ = 25.30 ± 1.96 * 8.17/$\sqrt{2880}$ = [24.70, 25.60]

Case 3: $\overline{x} \pm t\alpha/_2 \frac{s}{\sqrt{n}}$ = 27.89 ± 1.96 * 7.31/$\sqrt{2880}$ = [27.62, 28.16]

4.2.2 Hypothesis testing

The decision making process to check claims about population based on information about samples. The purpose of hypothesis test is to determine whether it is appropriate to reject or not to reject the null hypothesis .the test statistics the sample statics upon which the decision to reject or fail to reject the null hypothesis is based. Initially ANOVA was conducted to compare the means of space mean speeds observed at three different cases.

$H_{o:}$ the population means of all cases under consideration are equal

H_1: the population means are not equal

At 95 % confidence interval the result of ANOVA analysis in table 4.1 for the equality of the means in the group shows p-value < 0.05(significant level) so we reject the null hypothesis and accept the alternative hypothesis. The hypothesis testing for the linear regression between the explanatory variable and predicted variable is conducted to test the null hypothesis is H_0: $\beta = \beta_0$ and the alternative hypothesis is H_α: $\beta \neq \beta_0$ depending on the value of $p^* < 0.025(\alpha/2)$ for all cases we reject the null hypothesis and accept the alternative hypothesis.

Table 4. 1 Result of ANOVA Test

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
case 1-1	48	1133.205	23.60843	13.789157
case 1-2	48	999.2117	20.81691	8.7500083
case 2-1	48	1269.67	26.45146	17.346021
case 2-2	48	1152.238	24.00496	15.488
case 3-1	48	1361.146	28.3572	7.8924908
case 3-2	48	1080.337	22.98589	14.758949

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1701.292	5	340.2585	26.178038	<0.05	2.24613
Within Groups	3652.399	281	12.99786			
Total	5353.691	286				

4.3 Passenger Car Unit Analysis

Under heterogeneous or partially heterogeneous conditions expressing traffic flow in terms of the vehicle per hour per lane is irrelevant as there is either no or partial lane discipline. One way to represent the heterogonous traffic flow is to express each vehicle category in terms of the interference it causes to the flow in terms of a standard vehicle category such as car, such a measure passenger car unit (PCU) or passenger car equivalent (PCE).

PCU values of any vehicle are sensitive to factors such as vehicle composition in the traffic mix and speed of the stream. Hence a single set of PCU could not be recommended for all types of traffic conditions (Chandra et al, 2000). A methodology to estimate PCE values as a function of vehicle projected area and speed. According to their methodology PCE of any particular vehicle is formulated

$$PCEi = \frac{Vc/Vi}{Ac/Ai} \quad (4.1)$$

When V_c and V_i=mean speed of car and type i vehicle respectively, in the traffic stream and; Ac and Ai = their respective projected rectangular areas (length*width) on the road.

The mean speed for different categories of vehicles has been calculated from the samples of speed recorded. The length and width of different categories of vehicles were measured using the tape meter to calculate their projected area using the equation of (Area=Length*Width). The overall calculation of the PCU factor is presented in table 4.1.

Table 4. 2 PCU Calculation

Vehicle class	Observed speed (km/hr.)			Standard deviation	Vehicle dimension			Vc/Vi	Ac/Ai	PCU
	Max.	Mean	Min.	σ	Length	Width	Area(m^2)			
Motor bicycle	40.91	24.16	12.43	6.99	1.65	0.7	1.16	0.8	5.84	0.1
Autorikshew	34.62	21.34	10.45	6.14	2.60	1.2	3.12	0.91	2.16	0.4
Auto(car)	41.54	19.33	11.09	6.45	4.5	1.5	6.75	1.00	1.00	1.0
Mini-bus	28.88	18.02	6.49	6.43	5	1.5	7.50	1.07	0.90	1.2
Pick-up	31.03	19.37	9.47	5.30	4.8	1.5	7.20	1.00	0.94	1.1
LCV	36.12	19.76	8.29	6.54	6	2.1	12.60	0.98	0.54	1.8
Medium Bus	29.19	19.28	9.24	4.65	7.7	2	15.40	1.00	2.30	2.3
Large Bus	25.09	18.58	7.81	3.92	12	2.55	30.60	1.06	4.80	4.8
Heavy Truck	28.92	19.05	12.18	4.09	8.5	2.5	21.25	1.01	3.20	3.2
Truck with Trailer	29.19	12.57	18.50	3.97	13.6	2.45	33.32	1.30	0.22	6.0

4.4 FD Model Investigations for Different Road Geometry

Three different cases are considered for this research. Five different FD models namely linear, polynomial 2 degrees, polynomial 3 degrees, Exponential and logarithmic models are developed from the empirical data. The correlation coefficient (R^2) and root mean square error (RMSE) is used for evaluating the good of fitness of different structures.

4.4.1. Roadway with and without Structural Median (Hawzen RA-Hawelti Junction)

For this case, a road from Hawzen Roundabout to Hawelti signalized intersection is selected as the study area

a) Road without Structural Median

Figure 4.1 represents the FDs model for the traffic flow without structural Median and Table 4.2 shows other details of these models. Among five models, the 3rd degree polynomial model is the best-fitted model as it has maximum R^2 (0.78) and least RSME (1.38) values. So the best-fitted structure of FD for this case is 3rd degree polynomial and the equation is

$$v = -0.096\rho^3 + 1.246\rho^2 - 7.45\rho + 36.21 \quad (4.3)$$

b) Road with Structural Median

Similarly, Figure 4.2 represents the FD model for the traffic flow at the structural median and table 4.3 shows the details of the FD model. Among the five models, polynomial 3rd degree has highest R^2 which is 0.635 and least RMSE value (2.22) so it is the best-fitted structure of FD for this case is polynomial 3rd degree and the equation is

$$v = -0.553\rho^3 + 4.409\rho^2 - 13.73\rho + 38.02 \quad (4.4)$$

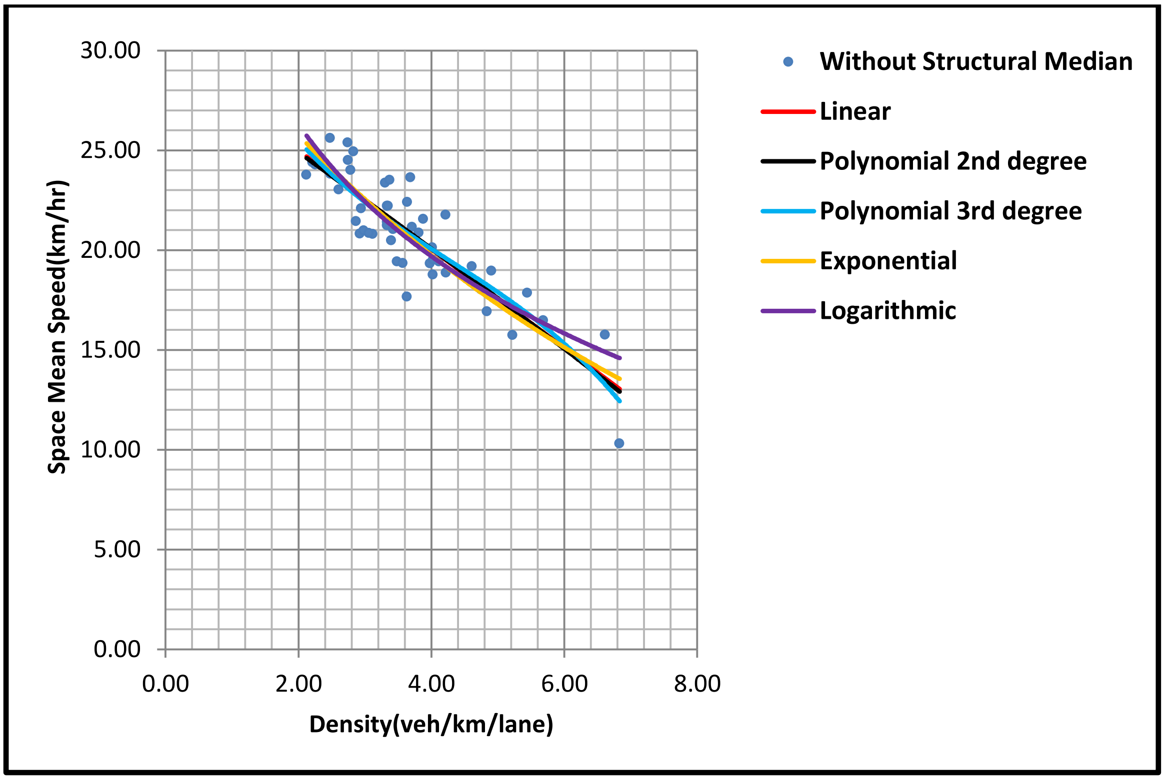

Figure 4. 1 FDs for Traffic Flow in Road without Structural Median

(Hawzen RA-Hawelti Junction)

Table 4.3 Model Fitting for Traffic Flow on Road Way without Structural Median

(Hawzen RA-Hawelti Junction)

Model	Equation	R^2		Free-flow Speed(km/hr)	Jam density (veh/km/lane)
Linear	$\nu = -2.474\rho + 29.93$	0.773	1.39	29.93	12.09
2nd Degree Polynomial	$\nu = -0.022\rho^2 - 2.297\rho + 29.5$	0.773	1.39	29.55	11.56
3rd Degree Polynomial	$\nu = -0.096\rho^3 + 1.246\rho^2 - 7.475\rho + 36.21$	0.777	1.38	36.21	18.34
Exponential	$\nu = 33.60e^{-0.13\rho}$	0.767	1.43	33.60	∞
Logarithmic	$\nu = -9.53 \ln \rho + 32.9$	0.748	1.46	∞	31.57

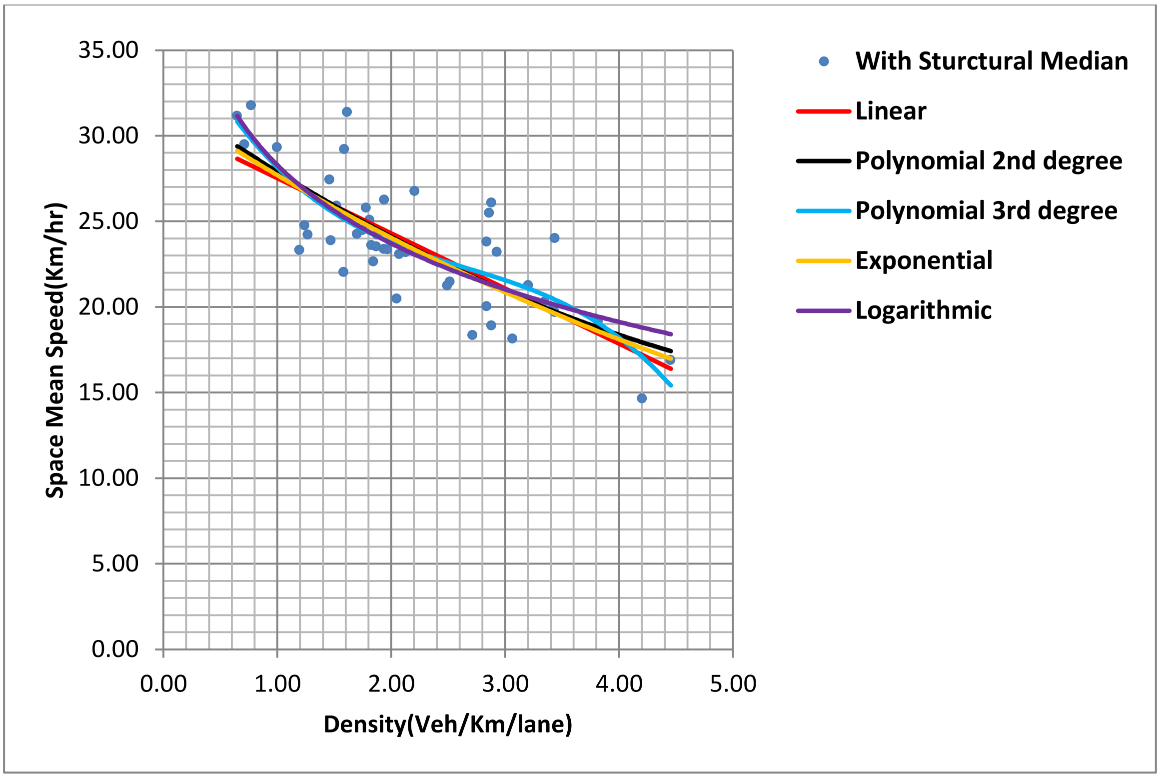

Figure 4. 1 FDs for the Traffic Flow in Roadway with Structural Median

(Hawzen RA-Hawelti Junction

Table 4. 4 Model fitting for traffic flow on the roadway with a structural median

Model	Equation	R^2	RMSE	Free-flow Speed(km/hr)	Jam density (veh/km/lane)
Linear	$\nu = -3.221\rho + 30.74$	0.600	2.32	30.74	9.54
2nd Degree Polynomial	$\nu = 0.313\rho^2 - 4.744\rho + 32.33$	0.607	2.30	32.33	7.58
3rd Degree Polynomial	$\nu = -0.553\rho^3 + 4.409\rho^2 - 13.73\rho + 38.02$	0.635	2.22	38.02	10.85
Exponential	$\nu = 31.91e^{-0.14\rho}$	0.621	2.30	31.91	∞
Logarithmic	$\nu = -6.61 \ln \rho + 28.28$	0.612	2.29	∞	72.12

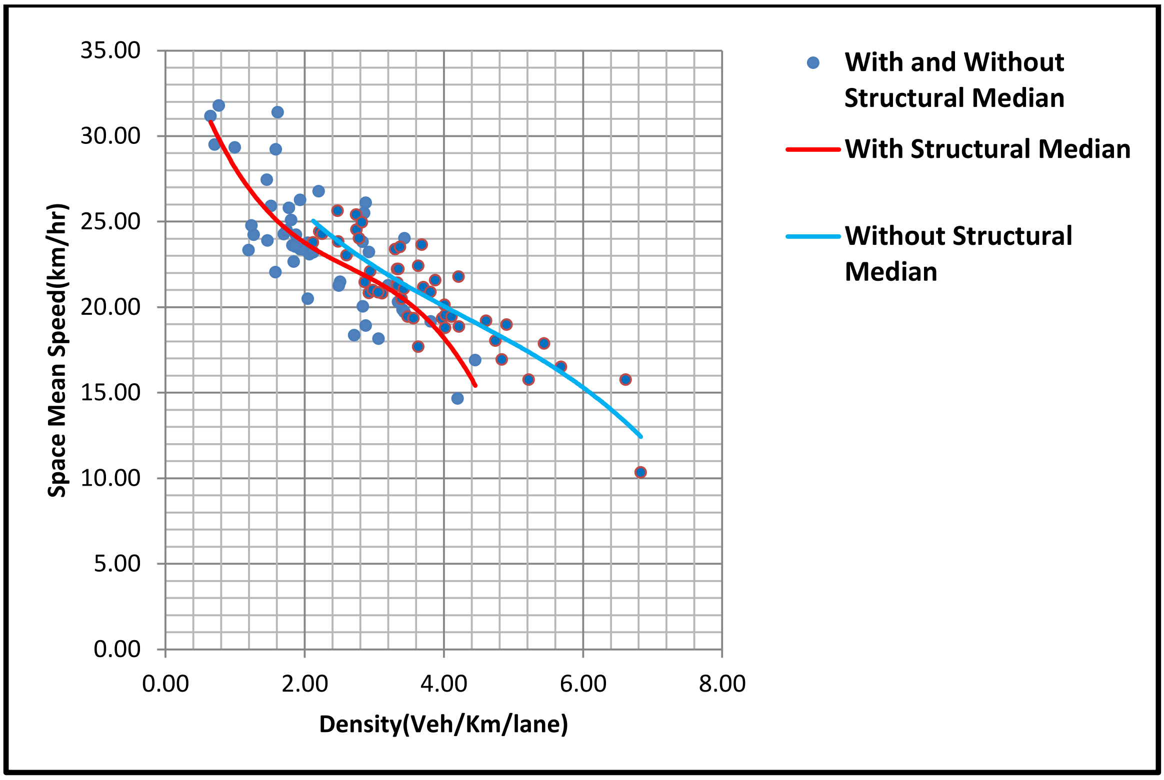

Figure 4. 2 Comparison between Traffic Flows on Roadway without & with Structural Median (Hawzen RA-Hawelti Junction)

c) Comparison between conditions(with and without structural median)

Among other models, the polynomial 3rd-degree model is the second-best model to satisfy the boundary condition and give the results for free-flow speed and jam density. So for comparison, the best-fitted model is taken and shown in figure 4.3. Free-flow speed in a location without a separated median is found 36.21 km/hr. from the model, whereas the value of free-flow speed in a location with a structural median is found 38.02 which is exceeded by 4.8% if there is structural median along the roadway. Similarly, jam density in a location without a structural median is found 18.34, and in a location with a structural median is found 10.85. Here it is found the jam density increased by 41% if there is no structural median. Due to the low speed, the density is higher in the roadway without a structural median. The comparison of parameters between the two conditions summarized in the table 4.5

Table 4. 5 Comparison of parameters for the road with and without structural median

Conditions	Free-flow speed (km/hr)	Jam density (Veh/km/lane)
without structural median	36.21	18.34
with structural median	38.02	10.85

4.4.2. Roadway with and without Footpath (Alula Abanega Airport to Quiha Sub-City Road)

For this case, the road from Alula Abanega Airport to Quiha sub-city is selected as a study area

a) Road with Footpath

Figure 4.4 represents the model for traffic flow with footpath and Table 4.4 shows other details of the model. Among the five models, the Exponential model has maximum R^2 (0.731) but the RSME (2.23) value is negligibly higher than the three models except for logrthmatric. So the best-fitted structure of FD for this case is Exponential and the equation is

$$v = 45.92e^{-0.27\rho} \quad (4.5)$$

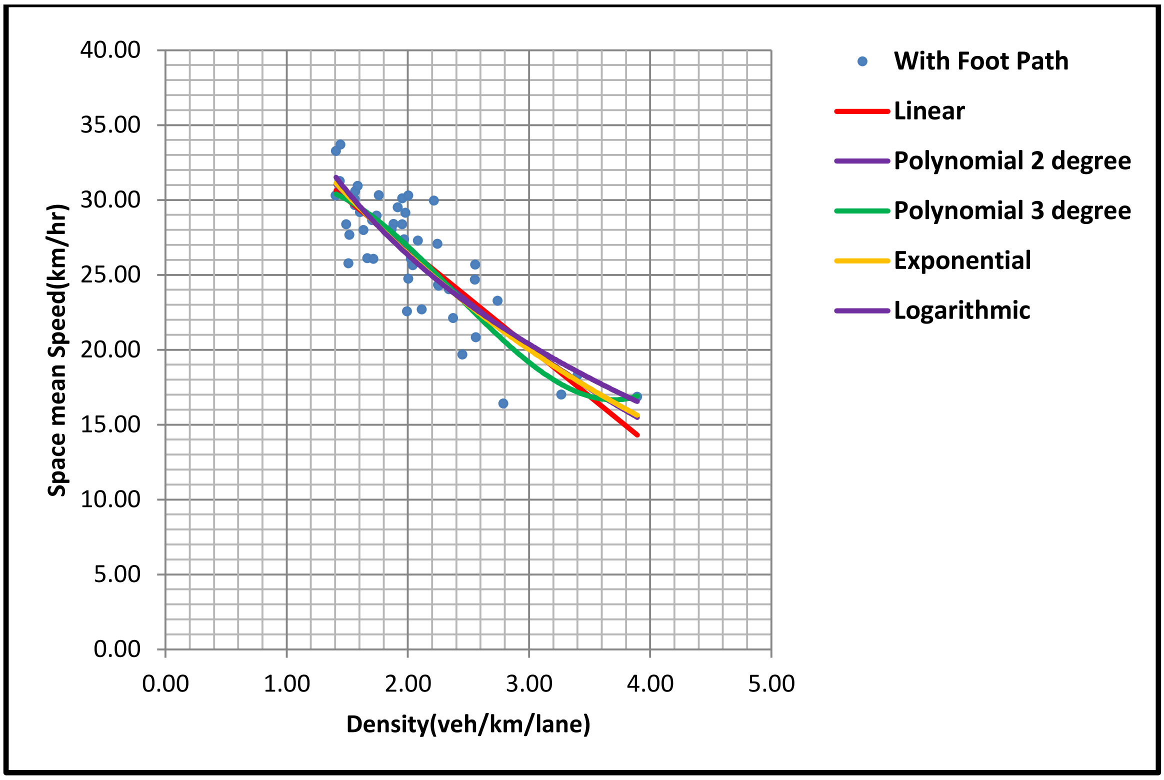

Figure 4. 3 FDs for Traffic Flow in Road with Foot Path

Table 4. 6 Model fitting for traffic flow on the roadway with a footpath

(From Alula Airport to Quiha)

Model	**Equation**	R^2	**RMSE**	**Free-flow Speed(km/hr)**	**Jam density (veh/mile/lane)**
Linear	$\nu = -6.558\rho + 39.84$	0.709	2.22	39.84	6.07
2nd Degree Polynomial	$\nu = 0.661\rho\text{^}2 - 9.74\rho + 43.43$	0.713	2.21	43.43	7.37
3rd Degree Polynomial	$\nu = 1.56\rho^3 - 11.26\rho^2 - 18.63\rho + 22.08$	0.723	2.48	22.08	8.43
Exponential	$\nu = 45.92e^{-0.27\rho}$	0.731	2.23	45.92	∞
Logarithmic	$\nu = -14.6 \ln \rho + 36.51$	0.704	2.24	∞	12.19

b) Road without Footpath

Similarly, Figure 4.5 represents the FD model for the traffic flow without footpath and table 4.5 shows the details of the FD model Among the five models, the exponential model has the highest R^2 (0.794) and least RMSE (2.26). So the best-fitted structure of FD for this case is Exponential and the equation is

$$v = 43.16e^{-0.27\rho} \quad (4.6)$$

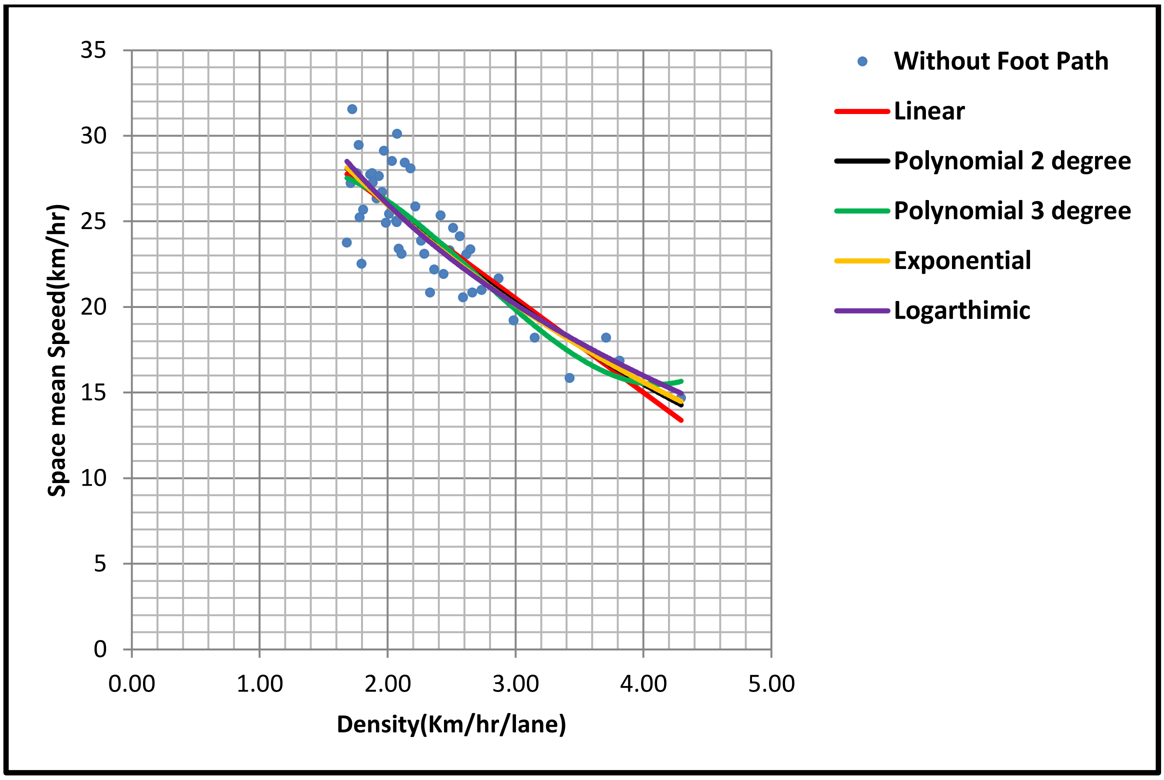

Figure 4. 4 FDs for Traffic Flow on Roadway without Foot Path

(From Alula Airport to Quiha)

Table 4. 7 Model fitting for traffic flow on a roadway without a footpath

Model	Equation	R^2	RMSE	Free-flow Speed(km/hr)	Jam density (veh/mile/lane)
Linear	$v = -5.496\rho + 36.99$	0.741	2.39	36.99	6.74
2nd Degree Polynomial	$v = 0.519\rho^2 - 8.393\rho + 40.74$	0.745	2.30	40.74	8.09
3rd Degree Polynomial	$v = 1.13\rho^3 - 9.15\rho^2 + 17.91\rho + 17.91$	0.753	2.59	17.91	4.41
Exponential	$v = 43.16e^{-0.25\rho}$	0.794	2.25	43.16	∞
Logarithmic	$v = -14.4 \ln \rho + 36.02$	0.738	2.26	∞	12.20

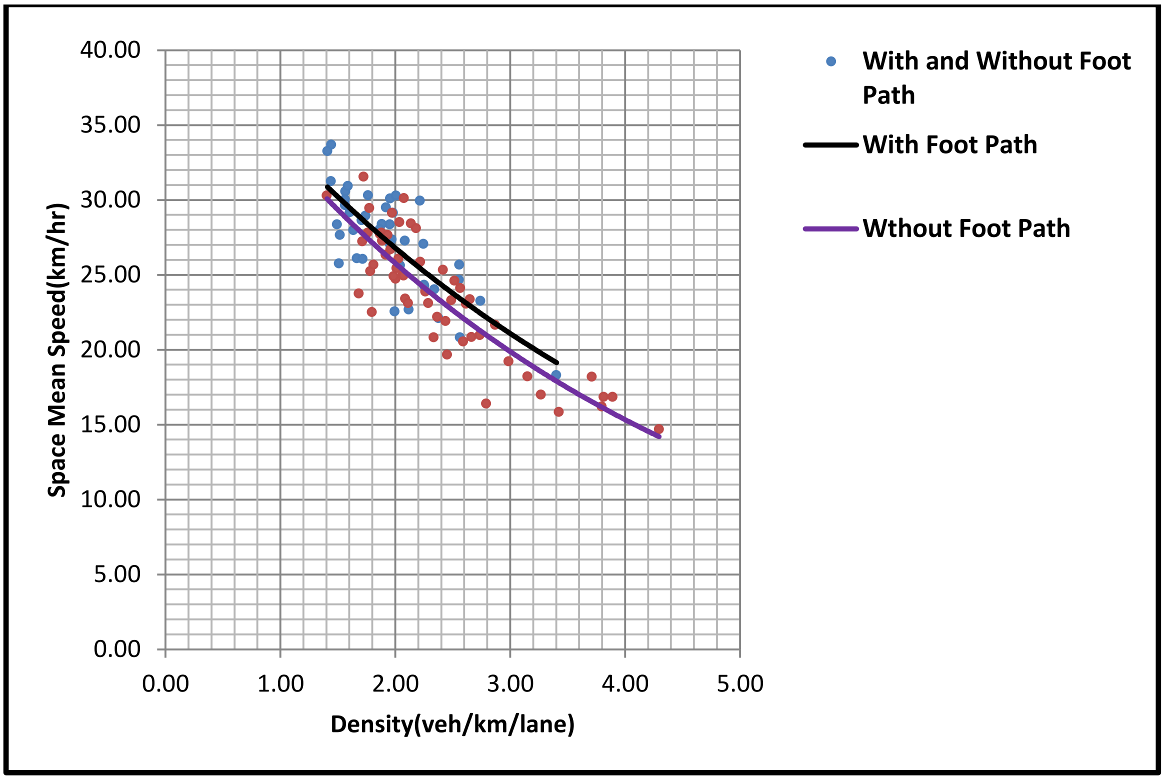

Figure 4. 5 Comparison between Traffic Flow on Road with and without Foot Path (Alula Airport to Quiha)

a) Comparison between conditions(with and without footpath)

In the case of both the best-fitted models for a roadway with and without footpath, jam density is infinity as the speed never reaches zero. So by comparing the RMSE, the 2nd-degree polynomial is the second-best model that gives both free flow speed and jam density. So for the comparison, the 2nd-degree polynomial model is considered and as shown in figure 4.6. Free-flow speed in a location with Footpath is found 43.43 km/hr from the model. Where, as it found 40.74 km/hr in a location without a footpath. So, free-flow speed is reduced by 6.19 %if there is no footpath on the roadway. Similarly, jam density in a location without footpath is found 8.08, and in a location with footpath is found 7.37. Here it is found the jam density is increased by 8.8 % if there is no footpath. Due to low speed, the traffic remains more compacted and thereby jam density is increased. The comparison of parameters between the two conditions summarized in the table 4.8

Table 4. 8 Comparison of parameters for the road with and without a footpath

Conditions	**Free-flow speed (km/hr)**	**Jam density (Veh/km/lane)**
With Foot Path	43.43	7.37
without Foot Path	40.74	8.08

4.4.3 Roadway with and without Road Side Activity (Encode-Martyrs Monument road)

For this case, the road from Encodo primary school around saint Rufael church to martyrs memorial compound is selected as a study area.

a) With road-side activity

Figure 4.7 represents the FDs model for traffic flow on the highway with the roadside market and Table 4.8 shows other details of the FD model. Among the five models exponential model modelled has maximum R^2 (0.60) but the RSME (2.84) value is negligibly higher than the three models except for logrthmatric. So the best-fitted structure of FD for this case is Exponential and the equation is

$$v = 30.6e^{-0.323\rho} \quad (4.7)$$

b) Without road-side activity

Similarly, Figure 4.8 represents the FD model for the traffic flow without the road-side market and Table 4.9 shows the details of the FD model Among the five models, the polynomial 3rd-degree model has the highest R2 (0.644) and least RMSE (2.26). So the best-fitted structure of FD for this case is Polynomial 3rd degree and the equation is:

$$v = -0.118\rho^3 - 1.446\rho^2 - 0.0429\rho + 32.97 \quad (4.8)$$

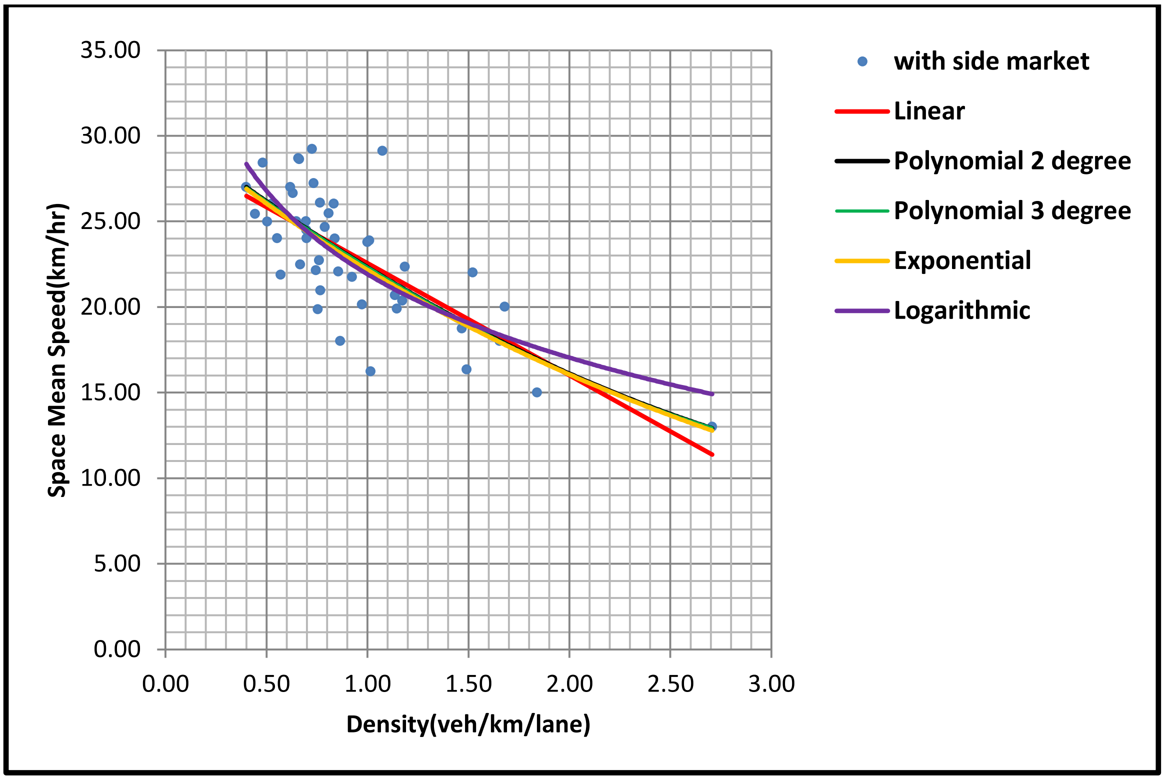

Figure 4. 6 FDs for Traffic Flow on Roadway with Road Side Activity

(Encodo to martyers monument)

Table 4. 9 Model fitting for traffic flow on a Roadway with Roadside Activity

(Encodo to martyers monument)

Model	Equation	R^2	RMSE	Free-flow Speed(km/hr)	Jam density (veh/mile/lane)
Linear	$\nu = -6.5432\rho + 29.096$	0.543	2.82	29.096	4.45
2nd Degree Polynomial	$\nu = 0.991\rho^2 - 9.184\rho + 30.52$	0.549	2.83	30.52	4.64
3rd Degree Polynomial	$\nu = 0.056\rho^3 + 0.741\rho^2 - 8.865\rho + 30.401$	0.548	2.83	30.40	21.68
Exponential	$\nu = 30.6e^{-0.323\rho}$	0.602	2.85	30.6	∞
Logarithmic	$\nu = -7.031\ \ln\rho + 21.92$	0.532	2.89	∞	22.59

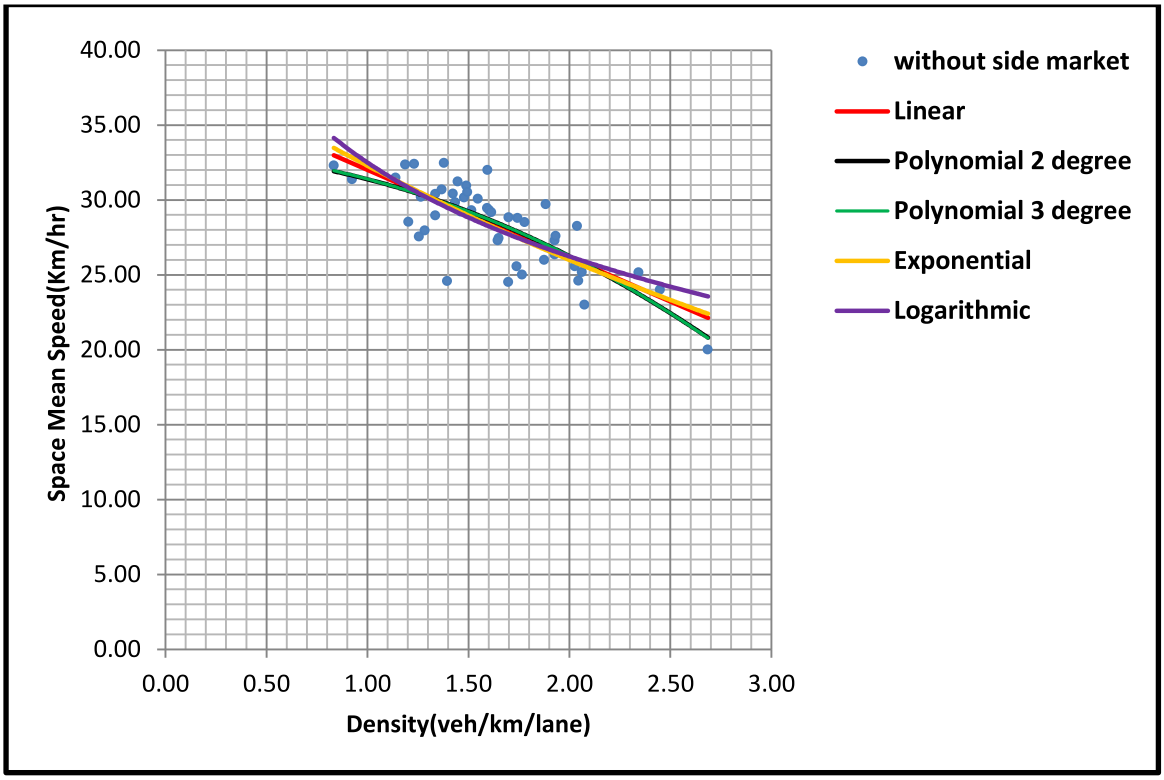

Figure 4. 7 FDs for Traffic Flow on Roadway without Road Side Activity

(Encodo to martyers monument)

Table 4. 10 Model fitting for traffic flow on a Roadway without Roadside Market

(Encodo to martyers monument)

Model	Equation	R^2	RMSE	Free-flow Speed(km/hr)	Jam density (veh/mile/lane)
Linear	$\nu = -5.859\rho + 37.86$	0.604	1.761	37.86	6.46
2nd Degree Polynomial	$\nu = -1.662\rho^2 + 0.146\rho + 33.19$	0.618	1.713	33.19	4.51
3rd Degree Polynomial	$\nu = -0.086\rho^3 - 1.212\rho^2 - 0.892\rho + 33.58$	0.619	1.712	33.58	4.33
Exponential	$\nu = 40.098e^{-0.217\rho}$	0.607	1.793	40.09	∞
Logarithmic	$\nu = -9.039\ln\rho + 32.49$	0.557	1.880	∞	32.49

c) Comparison between conditions(with and without road side)

For the first case, the jam density approaches to infinity since the speed never reaches zero. Among the other models, the 2nd-degree polynomial is the second-best fitted model that also satisfies the boundary condition and gives free-flow speed and jam density.so for the comparison, 2^{nd}-degree polynomial models were considered and shown in figure 4.9. Free-flow speed for traffic flow with the roadside market is found 30.52 km/hr whereas it is found 33.58 km/hr in case of traffic flow in the roadway without roadside market.so free flow is increased by 9.11% due to the absence of the roadside market. Similarly, jam density in case of traffic flow in the roadway without a roadside market is 4.33, and in case of traffic flow in the roadway with the roadside market, jam density is 4.64. Here it is found the jam density is increased by 6.68% if there is a roadside market on the highway. Due to low free-flow speed traffic remains compact in the case of the roadside market and jam density is increased. The comparison of parameters between two conditions is presented in table 4.11

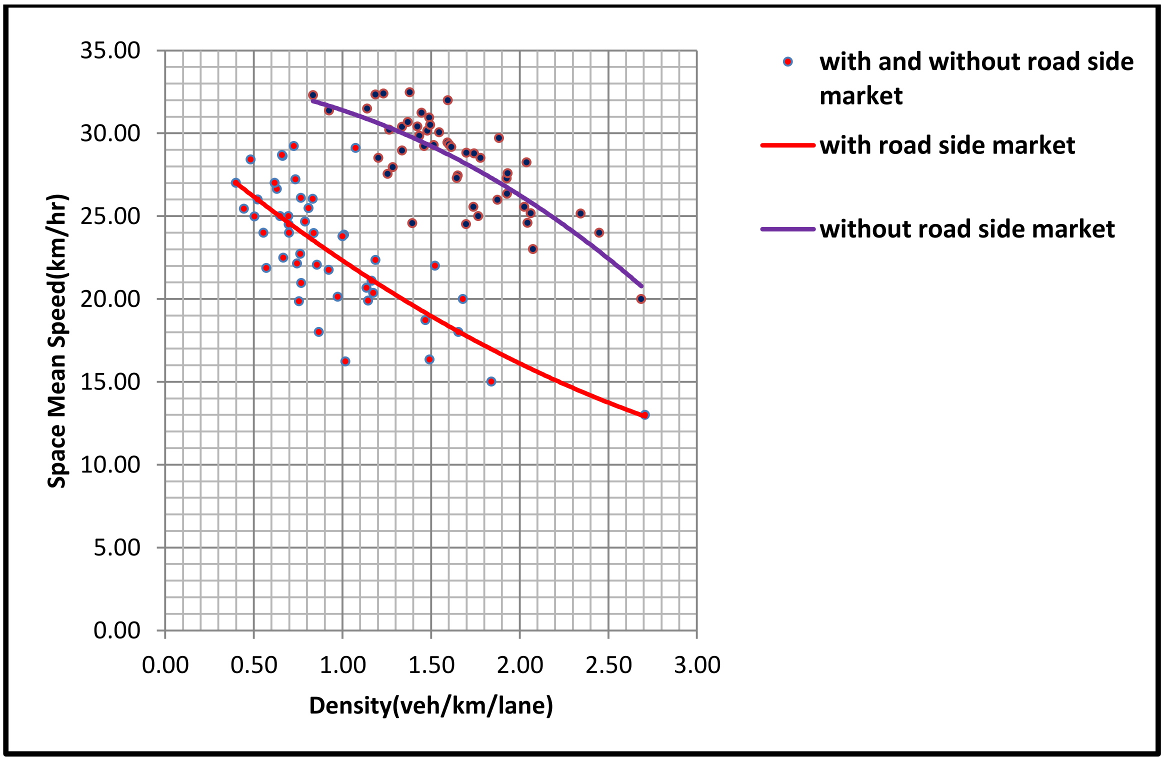

Figure 4. 8 Comparisons between Traffic Flow on Road with and without Road Side Market

Table 4. 11 **C**omparison of parameters for the road with and without road-side activity

Conditions	Free-flow speed (Km/hr.)	Jam density (Veh/km/lane)
With Roadside Market	30.52	4.64
without Road Side Market	33.58	4.33

4.5 FD Model Validation

After the model is developed, it is mandatory to verify the developed model the predicted density of vehicles applying traffic flow and speed as input for the model must be verified. The detail analysis is conducted by ANOVA and presented in annex

Table 4. 12 Statistical analysis, ANOVA test of the model

cases	F-test		t-test			R^2	R_{adj}^2	Remark
	F-value	P-value	Coefficient	t-value	p-value			
With median structure	69.21	<0.05	30.74	33.29	<0.05	0.60	0.59	Significant
			-3.22	-8.32	<0.05			
Without-median structure	156.45	<0.05	29.93	39.55	<0.05	0.77	0.76	Significant
			-2.47	-12.51	<0.05			
With foot path	112.07	<0.05	39.85	30.48	<0.05	0.71	0.70	Significant
			-6.56	-10.59	<0.05			
Without foot path	132.14	<0.05	36.99	31.69	0.05	0.74	0.73	Significant
			-5.49	-11.49	<0.05			
With side market	70.27	<0.05	37.85	32.57	<0.05	0.60	0.59	Significant
			-5.86	-8.38	<0.05			
Without side market	53.41	<0.05	29.09	31.63	<0.05	0.54	0.53	Significant
			-6.54	-7.38	<0.05			

Table 4.12 demonstrates the statistical analysis of the model. The validation process in regression analysis consist three tests; the F-test, R^2 test and t-test. As we can read from

table for 95% confidence interval where α=5%, the F-test is significant at 5% and the F-statistics is zero means its probability of exceeding 5% is zero. This implies we reject the null hypothesis and accept the alternative hypothesis. So, far the model has satisfied the two validity tests but still one test of significant is remaining the t-test. The model show significant in F-test and R^2 test it is possible to proceed with the third and final test, t-test. It is a test of significant for individual explanatory variable x1, x2 and constant term. The t-statistics is found by coefficient (unstandardized) by standard error.as we can read from table all the independent variables show that t-test is significant at 95% confidence interval. This implies we reject the null hypothesis and accept the alternative hypothesis.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The thesis studied the shape and structure of FD for speed-density relationship for different road geometry and operating condition. It is also investigated the trend of flow parameters, i.e. the nature of changing flow parameters due to change in road geometry. The research conducted at heterogonous and non-lane based traffic conditions of Mekelle city. Free-flow speed and jam density obtained for different conditions that have been obtained from this thesis will provide a guideline to estimate highway capacity which will be required for better geometric design of new roads. Two different cases are considered for this thesis at two different study segments; each study segment consists of two different geometric conditions and operating condition. Five FD models namely linear, 2nd-degree polynomial, 3rd-degree polynomial, exponential and logarithmic were plotted using regression. The correlation coefficient (R^2) and root mean square error (RMSE) was used for evaluating the fitness of different FD model. For case 1 it is found that 3rd-degree polynomial is the best-fitted model for a roadway with and without a structural median. For case 2 the exponential model is the best-fitted model for a roadway with and without a footpath. For case 3 polynomial 2nd degrees is the best-fitted model for a roadway with a roadside activity and the exponential model is the best-fitted model for roadway without roadside activity. The flow parameters also change with the road geometry for case 1 the free-flow speed for roadway without structural median is found 36.21 and free-flow speed for roadway without structural median is 38.02, this shows the free flow speed is reduced by 4.8% if there is no structural median in the roadway. The jam density for roadway without structural median is found 18.34 and for with structural median is 10.85.the jam density increased by 41% if there is no structural median in the roadway. For case 2 the free-flow speed for roadway without footpath is 40.74 and for a roadway with footpath is 43.43, this indicates the speed is reduced by 6.19% if there is no footpath along the roadway. The jam density for a roadway with footpath is 7.37 and for roadway without is 8.08.the jam density is increased by 8.8 % due to side friction if there is no footpath along the roadway. Similarly, for case 3 the free-flow speed for roadway without a roadside activity is 33.58 and for a roadway with a roadside activity is 30.52, this indicates the speed is reduced by 9.11% if there is roadside activity along the highway. The jam density for roadway without a roadside activity is 4.33 and for a roadway with the road side activity is 4.64.the jam density is increased by 6.68 % due to roadside activity along the highway.

Table 5. 1 Best fitted FD models

cases	Geometric condition (operating condition)	Best fitted model	R^2	RSME	Free-flow Speed(km/hr)	Jam density (veh/km/lane)
1	With structural median	$v = -0.096\rho^3 + 1.246\rho^2 - 7.475\rho + 36.21$	0.635	2.22	38.02	10.85
	Without Structural median	$v = -0.096\rho^3 + 1.246\rho^2 - 7.475\rho + 36.21$	0.777	1.38	36.21	18.34
2	With footpath	$v = 0.661\rho^2 - 9.74\rho + 43.43$	0.713	2.21	43.43	7.37
	Without foot path	$v = 0.519\rho^2 - 8.393\rho + 40.74$	0.745	2.30	40.74	8.09
3	With road side activity	$v = 0.991\rho^2 - 9.184\rho + 30.401$	0.549	2.83	30.52	4.64
	Without road side activity	$v = -0.086\rho^3 - 1.212\rho^2 - 0.892\rho + 33.582$	0.619	1.712	33.58	4.33

5.2 Recommendations

The investigations carried out about FD lasts for more than 80 years in the developed country after the first pioneering study held by Greenshield in the 1930s. But it is very hard to find enough study conducted to model FD for non-lane based heterogonous traffic in developing countries. This s is mainly due to difficulty data collection and processing and wide variations of drive and population, vehicle and traffic environment. Even though the current research tries to focus its effort in this sector it cannot be viewed as a complete understanding of FD model for high complex heterogonous traffic .this research focus in developing deterministic speed- density FD models which lack the power to address the uncertainty brought by random factors in traffic flow .so there is research gap in developing stochastic speed-density relationship. The recommendations provided for future research are shown below.

1. It is difficult to count the recorded data manually so video processing techniques or vehicle classifier software can be applied to count and classify vehicles, and to measure their speed.
2. Stochastic parameters can be added to the equation to include the uncertainty missing from the modelled FDs and to increase the accuracy.
3. The study of FD can be incorporated with the performance evaluation and capacity instead of traffic and geometric condition.
4. Various agencies use FD for network management and signal control, so there is a gap of research for modelled FD in signalized intersections

REFERENCES

AACRA. (2003).Addis Ababa City Road Authority (AACRA): Geometric Design Manual

Ardekani.S & Ghandhari M., A Modified Greenberg Speed-flow Traffic Model .Technical Report #357, Dept. of Mathematics, University of Texas at Arlington, USA, 2008.

Castillo, J., M. Del, & Benitez, F. G. (1995). On the functional form of the speed-density Relationship: General theory. Transportation Research Part B: Methodological 29B, 373–389.

Chari, S., R., & Badarinath, K. M. (1983). Study of mixed traffic stream parameters through time lapse photography. Highway Research Bulletin, Indian Roads Congress Vol. 20, pp.57-83.

Chandra, S., & P.K, S. (2000). Dynamic PCU estimation of capacity on urban roads. *Indian Highways* 20, 17-28.

Del Castillo, J., M., Benitez, F., G. (1995). On the functional form of the speed-density Relationship-I: General theory. Transportation Research, 29(B), 5, 373-389.

Drake, J. S., Schofer, J. L., & May, A. D. (1967). A statistical analysis of speed-density Hypotheses. Highway Research Record 156, 53–87.

Drew, D. R. (1968). Traffic Flow Theory and Control. McGraw-Hill Book Company, Chapter 12. 187

Edie, L. C. (1961). Car-following and steady-state theory for non-congested traffic. Operations Research, 9(1), 66-76.

FHWA. (2018). Traffic Data Computation Method; Pocket Guide, Inc., Washington, Dc, FHWA-PL-18-027

Gaddan, K.H & Rao, R.K (2019).Speed-density functional relationship for heterogonous traffic data: a statistical and theoretical investgetion, 27(1):61-74

Gaurav, H., P., Varsha. V, & Ramachandera, R. (2014). Determinations of Sample for Speed Measurement on Urban Arterials. 11th Transportation planning and implementation Methodologies' for Developing countries, (pp. 384-390). Mumbai, India.

Geroliminis, N., & Daganzo, F. C. (2008, Feburary 8). Existence of urban-scale macrscopic fundmental diagram:some expermental findings. *Transportation Reserch* , 759-770

Greenberg, H. (1959). An analysis of traffic flow. Operations research, 7(1), 78-85.

Greenshields, B. D. (1935). A study of traffic capacity. Highway Research Board Proceedings Vol. 14, 448-481.

Hegyi, A., De Schutter, B., & Hellendoorn, H. (2005b). Model predictive control for optimal Coordination of ramp metering and variable speed limits. Transportation Research Part C: Emerging Technologies, 13(3), 185-209.

Hegyi, A., De Schutter, B., & Hellendoorn, J. (2005a). Optimal coordination of variable speed Limits to suppress shock waves. IEEE Transactions on Intelligent Transportation Systems,6(1), 102-112.

Herman, R., & Rothery, R. W. (1965). Car following and steady-state flow. In Proceedings of The 2nd International Symposium on the Theory of Traffic Flow.

Highway Capacity Manual, Transport Research Board, National Research council, Washington,D.C, 2000

Lekariap, E. M. (2015). A macroscopic fundamental diagram. American journal of civil Engineering, *vol.3*, 150-156.

Lele, Z., Timothy, M. G., & Jan, d. G. (2013). A comparative study of macroscopic Fundamental diagrams of arterial road network governed by adaptive traffic signal system. Transportation Research *Part B*, 1-23.

Mac Nicholas, Michael J. (2008) A simple and pragmatic representation of traffic flow. In Symposium on The Fundamental Diagram: 75 years (Woods Hole, MA), Transportation research Board.

Papageorgiou, M., Blosseville, J. M., & Hadj-Salem, H. (1989). Macroscopic modelling of Traffic flow on the Boulevard Peripherique in Paris. Transportation Research Part B: Methodological, 23(1), 29-47.

Pipes, L. A. (1953). An operational analysis of traffic dynamics. Journal of applied physics, 24(3), 274-281. PTV, AG. (2010, 2012). VISSIM 5.40 User Manual. Karlsruhe, Germany.

Thankappan Ajitha, Tamut Yamem & Vanajakshi Lelitha (2010). Traffic Stream modelling under heterogeneous Traffic Conditions, Traffic and Transportation Studies © 2010 ASCE/401

Underwood, R. T. (1961). Speed, volume and density relationships: Quality and Theory of Traffic Flow, Yale Bureau of Highway Traffic, New Haven, Conn., 141-188.

Van Aerde, M. (1995). Single regime speed-flow-density relationship for congested and Un-congested highways. In 74th Annual Meeting of the Transportation Research Board, Washington, DC (Vol. 6).

Zhang, H. M. (2002). A non-equilibrium traffic model devoid of gas-like behaviour. Transportation Research Part B: Methodological, 36(3), 275-290

APPENDIX-I: Speed, Flow and density data

Data for Road way with Structural Median

Location of study site: Hawzen round about to Hawelti signalized intersection

Date of video recording: 22th April 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(veh/lane)	S.M.S(km/hr)	density(veh/km/lane)
45.29	23.38	1.94
72.89	25.49	2.86
67.64	19.85	3.41
75.12	26.08	2.88
67.96	23.21	2.93
68.10	21.26	3.20
75.21	16.89	4.45
73.03	19.14	3.82
82.49	24.01	3.44
67.52	23.80	2.84
67.68	19.69	3.44
55.61	18.13	3.07
41.74	22.64	1.84
53.97	21.46	2.51
47.75	23.06	2.07
67.90	20.29	3.35
52.98	21.25	2.49
61.51	14.63	4.20
56.84	20.02	2.84
54.40	18.89	2.88
50.87	26.25	1.94
39.34	25.89	1.52
46.38	29.20	1.59
50.64	31.38	1.61
30.72	24.21	1.27
48.61	23.75	2.05
45.95	23.35	1.97
49.32	23.19	2.13
30.66	24.75	1.24
40.03	27.43	1.46
41.26	24.25	1.70
45.50	24.22	1.88
27.86	23.31	1.20

43.13	23.60	1.83
49.75	18.34	2.71
42.76	24.48	1.75
35.09	23.88	1.47
45.36	25.08	1.81
41.90	20.46	2.05
34.84	22.02	1.58
58.99	26.75	2.20
45.84	25.78	1.78
43.91	23.51	1.87
49.31	23.23	2.12
24.45	31.76	0.77
29.28	29.32	1.00
20.99	29.48	0.71
20.18	31.16	0.65

Data for Road way without Structural Media\

Location of study site: Hawzen round about to Hawelti signalized intersection

Date of video recording: 22th April 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(veh/hr/lane)	S.M.S(km/hr)	density(veh/km)
78.44	21.15	3.71
91.74	21.77	4.21
104.19	15.75	6.62
82.19	15.73	5.22
93.01	18.96	4.91
93.70	16.48	5.68
64.81	20.80	3.12
97.12	17.85	5.44
88.51	19.19	4.61
60.89	20.82	2.93
79.51	20.86	3.81
81.50	22.41	3.64
85.51	18.03	4.74
81.81	16.92	4.84
64.20	17.67	3.63
59.15	23.82	2.48
67.66	19.43	3.48
69.62	25.39	2.74
53.95	24.39	2.21
76.92	19.33	3.98
70.44	10.31	6.83
62.61	20.99	2.98
69.53	20.48	3.40
50.42	23.76	2.12
63.40	25.61	2.48
67.30	24.50	2.75
65.00	22.08	2.94
61.50	21.45	2.87
69.00	19.34	3.57
77.20	23.36	3.30
74.00	22.21	3.33
75.50	18.77	4.02
54.70	24.28	2.25
70.50	24.94	2.83

63.80	20.84	3.06
83.60	21.55	3.88
74.40	22.21	3.35
60.00	23.02	2.61
66.90	24.01	2.79
78.60	19.53	4.03
71.40	21.41	3.34
87.10	23.64	3.68
79.60	18.86	4.22
80.80	20.13	4.01
70.80	21.23	3.33
79.30	23.51	3.37
79.90	19.42	4.11
72.10	21.04	3.43

Data for Road way with Foot Path

Location of study site: Alula Abanega Airport to Quiha sub-city

Date of video recording: 21th October 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(veh/hr/lane	S.M.s(Km/hr)	density(veh/km/lane)
45.00	31.25	1.44
48.65	33.67	1.44
42.37	28.36	1.49
38.89	25.74	1.51
42.00	27.65	1.52
47.89	30.56	1.57
49.09	30.92	1.59
46.87	29.17	1.61
43.50	26.08	1.67
46.96	30.03	1.56
46.87	33.24	1.41
45.75	27.98	1.64
53.42	30.29	1.76
58.82	30.08	1.96
48.92	28.64	1.71
55.43	28.36	1.95
56.82	27.26	2.08
53.43	28.37	1.88
53.91	27.35	1.97
52.40	28.04	1.87
54.71	24.25	2.26
48.00	22.67	2.12
44.72	26.04	1.72
52.50	22.09	2.38
46.35	29.63	1.56
60.75	27.05	2.25
57.75	29.13	1.98
63.00	24.65	2.56
52.31	25.62	2.04
54.75	24.32	2.25
53.37	20.82	2.56
45.00	22.54	2.00
50.45	28.94	1.74
63.75	23.24	2.74

52.87	27.06	1.95
65.62	25.66	2.56
56.25	24.02	2.34
56.59	29.48	1.92
66.37	29.94	2.22
62.25	18.29	3.40
60.75	30.27	2.01
65.54	16.83	3.89
48.21	19.66	2.45
55.51	16.98	3.27
45.72	16.38	2.79
49.59	24.73	2.01
52.87	26.07	2.03
42.57	30.27	1.41

Data for Road way with Foot Path

Location of study site: Alula Abanega Airport to Quiha sub-city

Date of video recording: 21th October 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(veh/hr/ln	S.M.S(Km/hr)	density(veh/km/ln
46.65	27.23	1.71
54.45	31.54	1.73
48.95	27.808	1.76
45.00	25.23	1.78
46.50	25.67	1.81
51.43	27.26	1.89
51.75	27.72	1.87
52.31	27.8	1.88
50.46	26.33	1.92
53.44	27.64	1.93
52.31	26.69	1.96
49.50	24.9	1.99
51.19	25.43	2.01
58.05	28.51	2.04
51.75	25.02	2.07
48.86	23.39	2.09
48.75	23.09	2.11
60.75	28.42	2.14
51.75	24.94	2.07
61.31	28.09	2.18
57.38	25.86	2.22
62.50	30.11	2.08
54.00	23.86	2.26
52.88	23.1	2.29
57.50	29.12	1.97
48.60	20.82	2.33
52.50	22.18	2.37
39.94	23.74	1.68
61.20	25.33	2.42
53.44	21.91	2.44
40.50	22.51	1.80
57.94	23.29	2.49
61.88	24.6	2.52
61.87	24.11	2.57

53.25	20.54	2.59
60.30	23.05	2.62
61.88	23.36	2.65
55.50	20.83	2.66
52.31	29.45	1.78
62.12	21.65	2.87
57.37	20.97	2.74
64.25	16.84	3.82
67.50	18.19	3.71
57.37	19.2	2.99
54.25	15.84	3.42
61.50	16.19	3.80
57.37	18.2	3.15
63.06	14.68	4.30

Data for Road way without Foot Path

Location of study site: Alula Abanega Airport to Quiha sub-city

Date of video recording: 21th October 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(veh/hr/ln	S.M.S(Km/hr)	density(veh/km/ln
46.65	27.23	1.71
54.45	31.54	1.73
48.95	27.808	1.76
45.00	25.23	1.78
46.5	25.67	1.81
51.43	27.26	1.89
51.75	27.72	1.87
52.31	27.8	1.88
50.46	26.33	1.92
53.44	27.64	1.93
52.31	26.69	1.96
49.53	24.9	1.99
51.19	25.43	2.01
58.05	28.51	2.04
51.75	25.02	2.07
48.86	23.39	2.09
48.75	23.09	2.11
60.75	28.42	2.14
51.75	24.94	2.07
61.31	28.09	2.18
57.38	25.86	2.22
62.51	30.11	2.08
54.00	23.86	2.26
52.88	23.1	2.29
57.5	29.12	1.97
48.6	20.82	2.33
52.5	22.18	2.37
39.94	23.74	1.68
61.2	25.33	2.42
53.44	21.91	2.44
40.5	22.51	1.80
57.94	23.29	2.49
61.88	24.6	2.52
61.87	24.11	2.57

53.25	20.54	2.59
60.35	23.05	2.62
61.88	23.36	2.65
55.5	20.83	2.66
52.31	29.45	1.78
62.12	21.65	2.87
57.37	20.97	2.74
64.25	16.84	3.82
67.57	18.19	3.71
57.37	19.2	2.99
54.25	15.84	3.42
61.52	16.19	3.80
57.37	18.2	3.15
63.06	14.68	4.30

Data for Road Way with Road Side Market

Location of study site: Encodo primary school around Rufeal church to Martyr's Monument Compound through Adi-Haki Market

Date of video recording: 4th November 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(Veh/hr/lane)	S.M.S(km/hr)	density(veh/km/lane)
33.60	20.00	1.68
19.00	28.63	0.66
16.20	25.00	0.65
13.30	24.00	0.55
13.70	28.41	0.48
10.80	27.00	0.40
20.00	26.09	0.77
20.05	27.22	0.74
31.30	29.12	1.07
33.50	22.00	1.52
26.50	22.34	1.19
21.70	26.03	0.83
24.10	23.87	1.01
12.60	24.98	0.50
24.60	21.10	1.17
16.80	26.64	0.63
35.20	13.00	2.71
23.80	23.79	1.00
27.60	15.00	1.84
29.80	18.00	1.66
18.90	28.68	0.66
17.40	25.00	0.70
16.70	27.00	0.62
17.10	24.49	0.70
17.30	22.71	0.76
11.30	25.44	0.44
16.80	24.00	0.70
13.60	26.00	0.52
15.60	18.00	0.87
16.50	16.22	1.02
15.00	22.48	0.67
16.50	22.14	0.75

15.00	19.86	0.76
16.10	20.97	0.77
12.50	21.87	0.57
19.60	20.13	0.97
27.50	18.73	1.47
23.90	20.36	1.17
21.20	29.22	0.73
22.80	19.89	1.15
20.10	21.75	0.92
19.50	24.67	0.79
24.40	16.35	1.49
20.10	23.98	0.84
18.90	22.06	0.86
23.50	20.67	1.14
20.60	25.47	0.81

Data for Road Way without Road Side Market

Location of study site: Encodo primary school around Rufeal church to Martyr's Monument Compound through Adi-Haki Market

Date of video recording: 4th November 2019

Time: 7:00am to 9:00am from 4:00pm to 6:00pm

Data type: Traffic flow and space mean speed at 5 minuet interval

Flow(Veh/hr/lane)	S.M.S(km/hr)	density(veh/km/lane)
51.05	31.99	1.59
42.82	29.83	1.43
55.57	29.70	1.88
46.53	30.05	1.55
46.91	29.44	1.59
62.90	27.28	1.93
64.25	23.00	2.08
47.09	29.32	1.60
51.80	25.55	2.03
69.81	20.00	2.69
57.60	28.24	2.04
51.99	25.16	2.06
44.80	32.47	1.38
34.35	24.58	1.40
38.41	32.34	1.19
34.35	28.52	1.20
38.20	30.20	1.26
53.32	27.58	1.93
39.94	32.39	1.23
45.26	31.22	1.45
43.37	30.40	1.42
44.45	29.29	1.52
46.12	30.94	1.49
35.92	31.48	1.14
45.38	27.44	1.65
34.61	27.54	1.26
50.33	24.60	2.04
44.94	27.28	1.65
50.81	26.34	1.93
50.75	28.50	1.78
50.21	28.79	1.74
44.62	30.14	1.48

26.10	32.29	0.83
41.60	24.51	1.70
50.63	25.99	1.87
28.21	31.38	0.93
47.12	29.18	1.61
40.66	30.39	1.34
60.32	24.00	2.45
42.00	30.68	1.37
45.60	30.50	1.49
54.00	25.00	1.77
42.70	29.22	1.46
63.67	25.14	2.34
35.93	27.95	1.28
51.40	25.55	1.74
49.01	28.82	1.70
38.70	28.95	1.34

APPENDEX –II: Traffic Volume Data

Case 1-1 Road without structural median

		With PCU factor morning peak										
		0.1	0.4	1.0	1.1	1.2	2.3	4.8	1.8		3.2	
No	T.interva	M.bycicle	auto-riksha	auto(car)	Pick-up(4W	Mini-bus	Medium bu	Large bus	LCV	Small Truc	Heavy Tru	TOTAL
1	0-5'	0.3	6.7	6.0	13.8	42.9	2.3	0.0	5.5	0	0.0	78.4
2	5-10'	1.2	8.8	22.0	14.9	33.4	2.3	0.0	9.1	0.0	0.0	91.7
3	10-15'	1.1	5.9	14	11	54.9	13.7	0.0	3.7	0	0.0	104.2
4	15-20'	0.0	8.8	17	9	40.5	0.0	0.0	3.7	0	3.2	82.1
~~5~~	~~20-25'~~	1.0	7.1	17	15	35.8	6.9	4.8	5.5	0	0.0	93.0
6	25-30'	1.0	5.9	13	11	38.2	4.6	9.6	7.3	0	3.2	93.7
7	30-35'	0.7	3.8	11	13	27.4	2.3	4.8	1.8	0	0.0	64.8
8	35-40'	0.5	6.7	13	11	44.1	4.6	4.8	7.3	0	3.2	97.1
9	40-45'	0.3	7.1	19	7	33.4	4.6	4.8	9.1	0	3.2	88.5
10	45-50'	0.3	4.2	10	5	34.6	0.0	0.0	3.7	0	3.2	60.9
11	50-55'	1.1	6.3	14	9	38.2	9.1	0.0	1.8	0	0.0	79.5
12	55-60'	0.8	6.3	7	9	31.0	2.3	0.0	9.1	0	15.8	81.3
13	60-65'	1.2	7.1	14	12	42.9	4.6	0.0	3.7	0	0.0	85.5
14	65-70'	0.5	5.4	8	9	40.5	4.6	0.0	7.3	0	6.3	81.7
15	70-75'	0.8	6.7	6	11	25.0	2.3	0.0	7.3	0	3.2	64.2
16	75-80'	1.8	3.8	9	6	32.2	0.0	0.0	5.5	0	0.0	59.2
17	80-85'	0.3	3.8	8	12	37.0	3.0	0.0	3.7	0	0.0	67.7
18	85-90'	0.3	8.0	16	12	33.4	0.0	0.0	0.0	0	0.0	69.6
19	90-95'	0.5	1.7	10	4	27.4	3.0	0.0	7.3	0	0.0	54.0
20	95-100'	0.4	4.6	17	7	31.0	2.3	0.0	14.6	0	0.0	76.9
21	100-105	1.0	6.3	12	18	28.6	0.0	0.0	3.7	0	0.0	70.4
22	105-110	0.5	5.0	7	10	33.4	0.0	0.0	3.7	0	3.0	62.6
23	110-115	0.4	3.4	9	13	29.8	2.3	4.8	3.7	0	3.2	69.5
24	115-120	0.3	4.2	7	11	23.8	2.3	0.0	1.8	0	0.0	50.4
						Evening peak						
25	0-5'	0.2	5.6	5	8.8	38.4	0	0	5.4	0	0	63.4
26	5-10'	0.3	6.8	9	9.9	26.4	2.3	0	12.6	0	0	67.3
27	10-15'	0.8	4.8	6	8.8	31.2	0	4.8	5.4	0	3.2	65.0
28	15-20'	0.6	6	5	7.7	33.6	2.3	0	5.4	0	0	61.5
29	~~20-25'~~	0.1	5.2	9	12.1	37.2	0	0	5.4	0	0	69.0
30	25-30'	0.5	4	10	16.5	36	0	4.8	5.4	0	0	77.2
31	30-35'	0.4	4.4	15	8.8	37.2	0	0	1.8	0	6.4	74.0
32	35-40'	0.3	4.4	8	5.5	39.6	0	9.6	7.2	0	0	75.5
33	40-45'	0.3	8	3	6.6	30	0	0	3.6	0	3.2	54.7
34	45-50'	0.2	4	7	9.9	40.8	0	0	5.4	0	3.2	70.5
35	50-55'	0.2	5.2	5	13.2	38.4	0	0	1.8	0	0	63.8
36	55-60'	0.3	4	8	13.2	42	0	4.8	7.2	0	3.2	83.6
37	60-65'	0.5	4.4	8	6.6	46.8	0	0	7.2	0	0	74.4
38	65-70'	0.5	5.2	12	7.7	26.4	0	0	1.8	0	6.4	60.0
39	70-75'	0.5	1.6	5	2.2	44.4	0	9.6	3.6	0	0	66.9
40	75-80'	0.2	7.2	10	4.4	45.6	0	4.8	0	0	6.4	78.6
41	80-85'	0.2	4.8	11	7.7	34.8	0	4.8	7.2	0	0	71.4
42	85-90'	0.3	6.4	10	9.9	43.2	6.9	0	7.2	0	3.2	87.1
43	90-95'	0.4	5.6	15	8.8	38.4	0	9.6	1.8	0	0	79.6
44	95-100'	0.7	5.2	10	12.1	43.2	4.6	0	1.8	0	3.2	80.8
45	100-105	0.7	6	8	12.1	32.4	0	4.8	3.6	0	3.2	70.8
46	105-110	0.3	3.6	11	5.5	51.6	2.3	0	1.8	0	3.2	79.3
47	110-115	0.2	5.2	8	6.6	50.4	0	0	5.4	0	3.2	79.9
48	115-120	0.3	5.2	12	6.6	43.2	0	4.8	0	0	0	72.1

Case 1-2 Road with structural median

				With PCU factor							
				Morning peak							
	0.1	0.4	1.0	1.1	1.2	2.3	4.8	1.8		3.2	
No	M.bycic	auto-riksha	auto(ca	Pick-up(4WI	Mini-bu	Medium bu	Large bu	LUV	Small Truck	Heavy Tru	TOTAL
1	0.4	1.3	9.0	5.3	20.4	2.3	4.8	1.8	0.0	0.0	45.3
2	1.0	3.4	11.0	12.8	24.0	4.6	14.4	1.8	0.0	0.0	72.9
3	0.4	0.4	12.0	14.9	27.6	0.0	9.6	1.8	0.0	0.0	67.6
4	0.8	2.5	16.0	6.4	25.2	4.6	9.6	3.6	0.0	6.4	75.1
5	0.4	2.5	13.0	13.8	20.4	4.6	9.6	3.6	0.0	0.0	68.0
6	0.8	2.1	16.0	9.6	24.0	0.0	4.8	10.8	0.0	0.0	68.1
7	0.1	1.7	18.0	21.3	26.4	2.3	0.0	5.4	0.0	0.0	75.2
8	0.3	2.5	15.0	13.8	34.8	0.0	4.8	1.8	0.0	0.0	73.0
9	0.7	0.8	15.0	16.0	27.6	9.2	9.6	1.8	0.0	0.0	82.5
10	0.4	1.7	16.0	17.0	25.2	0.0	0.0	7.2	0.0	0.0	67.5
11	0.7	2.1	14.0	14.9	22.8	6.9	0.0	5.4	0.0	0.0	67.7
12	0.5	1.7	14.0	9.6	21.6	4.6	0.0	3.6	0.0	0.0	55.6
13	0.4	0.8	12.0	6.4	13.2	2.3	4.8	1.8	0.0	0.0	41.7
14	0.4	0.8	11.0	8.5	19.2	9.2	4.8	0.0	0.0	0.0	54.0
15	0.3	2.5	8.0	4.3	24.0	6.9	0.0	1.8	0.0	0.0	47.7
16	0.4	3.8	9.0	8.5	25.2	4.6	9.6	3.6	0.0	3.2	67.9
17	0.1	1.3	13.0	9.6	18.0	4.6	0.0	0.0	0.0	6.4	53.0
18	0.3	3.4	12.0	9.6	27.6	6.9	0.0	1.8	0.0	0.0	61.5
19	0.5	4.2	13.0	14.0	22.8	2.3	0.0	0.0	0.0	0.0	56.8
20	0.4	4.6	9.0	9.6	24.0	0.0	0.0	3.6	0.0	3.2	54.4
21	0.5	0.8	8.0	6.4	26.4	6.9	0.0	1.8	0.0	0.0	50.9
22	1.1	2.1	4.0	7.5	19.2	2.3	0.0	0.0	0.0	3.2	39.3
23	1.0	2.1	7.0	5.3	19.2	4.6	0.0	7.2	0.0	0.0	46.4
24	0.7	1.7	10.0	9.6	19.2	2.3	0.0	7.2	0.0	0.0	50.6
				Evening peak							
25	0.3	1.3	8.0	3.2	14.4	0.0	0.0	3.6	0.0	0.0	30.7
26	0.3	3.4	12.0	9.6	21.6	0.0	0.0	1.8	0.0	0.0	48.6
27	0.1	2.1	12.0	5.3	22.8	0.0	0.0	3.6	0.0	0.0	46.0
28	0.7	2.5	8.0	5.3	21.6	4.6	4.8	1.8	0.0	0.0	49.3
29	0.3	2.9	10.0	4.3	13.2	0.0	0.0	0.0	0.0	0.0	30.7
30	1.0	3.4	3.0	8.5	19.2	0.0	0.0	1.8	0.0	3.2	40.0
31	1.4	0.0	6.0	6.4	21.6	2.3	0.0	3.6	0.0	0.0	41.3
32	0.4	0.8	7.0	7.5	25.2	4.6	0.0	0.0	0.0	0.0	45.5
33	0.4	1.3	4.0	6.4	10.8	0.0	0.0	1.8	0.0	3.2	27.9
34	0.3	0.8	9.0	8.5	20.4	0.0	0.0	0.0	0.0	3.2	43.1
35	0.3	0.4	8.0	4.3	26.4	0.0	0.0	7.2	0.0	3.2	49.8
36	0.4	1.3	4.0	6.4	21.6	0.0	0.0	1.8	0.0	6.4	42.8
37	0.1	0.8	4.0	8.5	16.8	0.0	4.8	0.0	0.0	0.0	35.1
38	0.3	2.1	3.0	6.4	25.2	0.0	4.8	3.6	0.0	0.0	45.4
39	0.0	0.4	5.0	9.6	22.8	2.3	0.0	1.8	0.0	0.0	41.9
40	0.0	0.4	3.0	5.3	25.2	0.0	0.0	0.0	0.0	0.0	34.8
41	0.3	2.9	9.0	9.6	24.0	0.0	9.6	3.6	0.0	0.0	59.0
42	0.5	0.8	4.0	4.3	18.0	0.0	9.6	5.4	0.0	3.2	45.8
43	0.5	1.7	2.0	6.4	22.8	2.3	0.0	1.8	0.0	6.4	43.9
44	0.1	2.5	5.0	4.3	27.6	0.0	4.8	1.8	0.0	3.2	49.3
45	0.0	1.3	2.0	3.2	18.0	0.0	0.0	0.0	0.0	0.0	24.5
46	0.3	1.7	2.0	2.1	16.8	0.0	0.0	0.0	0.0	6.4	29.3
47	0.1	1.3	2.0	3.2	14.4	0.0	0.0	0.0	0.0	0.0	21.0
48	0.3	1.7	3.0	2.1	10.8	2.3	0.0	0.0	0.0	0.0	20.2

Case 2-1 Road with foot path

		With PCU factor										
		Morning peak										
		0.1	0.4	1	1.1	1.2	2.3	4.8	1.8	3.2	6	
No	T.interval	M.bycicle	auto-rikshaw	auto(car)	Pick-up(4WD)	Mini-bus	Medium bus	Large bus	LcV	H.Truck	Truck.Trailer	total
1	0-5'	0.3	2.4	2	5.5	13.2	0	9.6	3.6	6.4	6	49
2	5-10'	0.1	3.2	0	6.6	10.8	0	4.8	1.8	3.2	6	36.5
3	10-15'	0.4	2	1	4.4	14.4	2.3	4.8	3.6	3.2	6	43
4	15-20'	0.1	1.2	0	3.3	9.6	0	9.6	1.8	3.2	0	28.8
~~5~~	~~20-25'~~	0.3	1.6	3	5.5	15.6	2.3	4.8	0	6.4	12	51.5
6	25-30'	0.2	2.4	4	8.8	8.4	2.3	9.6	0	0	12	48.6
7	30-35'	0.1	2.8	2	6.6	9.6	0	4.8	1.8	6.4	6	40.1
8	35-40'	0	3.6	3	5.5	6	0	9.6	1.8	9.6	0	39.1
9	40-45'	0.2	1.6	3	5.5	13.2	0	4.8	0	6.4	6	41.6
10	45-50'	0.1	2	1	6.6	12	0	9.6	1.8	0	12	45.1
11	50-55'	0.3	3.2	2	4.4	10.8	0	14.4	3.6	9.6	6	54.3
12	55-60'	0.1	2.4	1	5.5	12	2.3	9.6	3.6	6.4	12	55.8
13	60-65'	0.1	0.8	2	3.3	10.8	0	0	1.8	9.6	6	34.4
14	65-70'	0.1	2.4	2	3.3	9.6	0	0	1.8	9.6	18	46.8
15	70-75'	0.1	0	0	2.2	13.2	0	4.8	0	9.6	0	29.9
16	75-80'	0	0.4	0	6.6	0	0	0	0	6.4	6	19.4
17	80-85'	0.1	0	0	2.2	12	2.3	0	1.8	6.4	6	30.8
18	85-90'	0.2	1.2	1	2.2	4.8	0	0	1.8	6.4	6	23.6
19	90-95'	0	2.4	0	1.1	7.2	0	0	3.6	9.6	12	35.9
20	95-100'	0	1.6	1	8.8	8.4	0	4.8	1.8	9.6	12	48
21	100-105'	0.2	1.6	1	3.3	8.4	0	4.8	0	6.4	6	31.7
22	105-110'	0	2	3	2.2	9.6	0	0	0	3.2	6	26.9
23	110-115'	0.1	1.2	2	4.4	12	2.3	0	1.8	3.2	0	27
24	115-120'	0.3	2	0	5.5	6	0	4.8	0	6.4	6	31
		Evening peak										0
25	0-5'	0.2	2.4	1	3.3	13.2	0	4.8	3.6	6.4	6	40.9
26	5-10'	0.1	3.2	2	5.5	10.8	0	0	1.8	0	6	29.4
27	10-15'	0.3	4	0	2.2	15.6	0	9.6	1.8	3.2	6	42.7
28	15-20'	0.2	1.2	2	3.3	9.6	0	4.8	1.8	3.2	0	26.1
29	~~20-25'~~	0.1	3.2	1	4.4	8.4	0	4.8	0	3.2	0	26
30	25-30'	0.3	4	3	5.5	12	0	4.8	3.6	6.4	6	45.6
31	30-35'	0.3	1.2	0	2.2	6	0	0	1.8	3.2	6	20.7
32	35-40'	0.3	3.2	1	1.1	9.6	2.3	4.8	5.4	9.6	6	44.2
33	40-45'	0.1	0.8	1	2.2	7.2	0	0	1.8	6.4	24	43.5
34	45-50'	0.4	1.2	0	2.2	8.4	0	0	1.8	12.8	0	26.8
35	50-55'	0.1	1.2	2	2.2	10.8	0	0	0	3.2	0	19.5
36	55-60'	0.2	2.8	0	2.2	8.4	0	0	0	0	12	25.6
37	60-65'	0	1.2	0	1.1	12	0	4.8	1.8	6.4	6	33.3
38	65-70'	0.1	1.6	2	3.3	6	0	0	1.8	3.2	0	18
39	70-75'	0	0.4	0	1.1	6	0	4.8	3.6	3.2	0	19.1
40	75-80'	0.1	1.6	0	2.2	9.6	0	4.8	1.8	0	18	38.1
41	80-85'	0	0.8	1	0	7.2	0	4.8	3.6	6.4	18	41.8
42	85-90'	0.1	1.2	1	9.9	6	2.3	0	1.8	0	6	28.3
43	90-95'	0.2	2	3	8.8	8.4	0	9.6	0	3.2	6	41.2
44	95-100'	0.3	1.2	1	11	7.2	2.3	9.6	1.8	0	0	34.4
45	100-105'	0.2	2	3	8.8	10.8	0	4.8	3.6	0	6	39.2
46	105-110'	0.3	2.4	0	5.5	8.4	2.3	0	1.8	3.2	6	29.9
47	110-115'	0.2	1.2	1	3.3	4.8	0	0	3.6	3.2	0	18.2
48	115-120'	0.1	2	2	3.3	9.6	0	4.8	0	0	0	22.7

Case 2-1 Road without foot path

		With PCU factor										
		0.1	0.4	1	1.1	1.2	2.3	4.8	1.8	3.2	6	
No		Morning peak										TOTAL
		M.bycicle	auto-rikshaw	uto(car	Pick-up(4WD)	Mini-bus	Medium bus	Large bus	LUV	heavy Truck	Truck with Trailer	
1	0-5'	0.2	4	9	6.6	21.6	0	4.8	1.8	0	6	54
2	5-10'	0.2	3.2	11	11	26.4	0	0	1.8	6.4	0	60
3	10-15'	0.4	4.8	12	15.4	24	0	9.6	3.6	0	12	82.7
4	15-20'	0.3	6.4	10	12.1	25.2	0	9.6	3.6	6.4	6	79.6
5	20-25'	0.5	7.2	13	15.4	22.8	2.3	9.6	0	3.2	0	74
6	25-30'	0.3	6	9	13.2	24	0	4.8	0	6.4	12	75.7
7	30-35'	0.1	5.6	10	11	20.4	0	4.8	3.6	3.2	0	59.6
8	35-40'	0.2	6.4	9	14.3	27.6	0	4.8	1.8	9.6	12	85.7
9	40-45'	0.4	4.8	11	9.9	30	0	14.4	1.8	6.4	6	84.7
10	45-50'	0.3	7.2	16	14.3	25.2	0	0	1.8	3.2	6	74
11	50-55'	0.5	6	14	13.2	22.8	2.3	4.8	1.8	6.4	12	83.8
12	55-60'	0.3	4	9	7.7	21.6	2.3	9.6	3.6	6.4	12	76.5
13	60-65'	0.3	3.6	12	6.6	13.2	2.3	14.4	1.8	0	0	55.1
14	65-70'	0.3	4.4	11	8.8	19.2	0	4.8	0	3.2	12	63.7
15	70-75'	0.2	3.2	8	12.1	24	2.3	0	1.8	3.2	18	72.8
16	75-80'	0.3	4.8	9	8.8	25.2	0	9.6	3.6	0	6	67.3
17	80-85'	0.1	3.6	13	9.9	18	4.6	0	0	0	12	61.2
18	85-90'	0.2	3.2	12	13.2	15.6	0	4.8	1.8	0	0	51.7
19	90-95'	0.4	4	13	15.4	22.8	2.3	0	0	3.2	12	73.1
20	95-100'	0.3	3.6	9	9.9	24	0	4.8	3.6	0	6	61.2
21	00-105	0.4	2.8	8	11	13.2	0	0	1.8	3.2	0	40.4
22	05-110	0.8	3.2	4	7.7	12	2.3	0	0	0	6	36
23	10-115	0.7	2	7	5.5	13.2	0	0	0	0	0	28.4
24	15-120	0.5	2.4	6	9.9	9.9	2.3	0	0	0	0	31
		Evening peak										
25	0-5'	0.2	5.2	9	14.3	14.4	0	4.8	3.6	3.2	12	66.7
26	5-10'	0.3	3.2	13	9.9	21.6	0	0	0	0	6	54
27	10-15'	0	6	10	5.5	22.8	0	0	1.8	6.4	0	54.3
28	15-20'	0.5	4.4	11	8.8	24	4.6	4.8	1.8	3.2	0	63.1
29	20-25'	0.2	6.8	10	15.4	30	0	9.6	0	0	18	90
30	25-30'	0.6	4.8	13	19.8	20.4	0	0	1.8	0	6	66.4
31	30-35'	0.5	5.6	16	14.3	21.6	2.3	0	3.6	0	6	70.8
32	35-40'	0.4	4	7	12.1	25.2	2.3	14.4	0	3.2	0	68.6
33	40-45'	0.3	5.2	14	17.6	22.8	0	0	1.8	0	6	67.7
34	45-50'	0.2	3.6	19	8.8	20.4	0	4.8	0	0	6	63.7
35	50-55'	0.2	4.4	18	15.4	26.4	4.6	0	3.6	6.4	6	85
36	55-60'	0.2	6	9	9.9	19.2	0	0	1.8	9.6	6	62.6
37	60-65'	0.5	3.2	10	12.1	14.4	0	4.8	0	0	0	45
38	65-70'	0.3	4	13	8.8	24	6.9	4.8	3.6	3.2	0	68.6
39	70-75'	0	3.6	8	9.9	22.8	2.3	0	1.8	3.2	0	51.6
40	75-80'	0	4	10	11	18	0	0	0	0	0	43.9
41	80-85'	0.1	2.8	9	9.9	12	0	14.4	3.6	3.2	0	55
42	85-90'	0	2	7	6.6	14.4	0	9.6	0	0	6	45.6
43	90-95'	0.1	4.4	5	6.6	10.8	2.3	0	0	0	6	35.2
44	95-100'	0.1	2.4	5	8.8	15.6	0	4.8	1.8	6.4	0	45.8
45	00-105	0	1.6	11	6.6	12	0	0	0	0	0	31.2
46	05-110	0.2	3.2	7	9.9	10.8	0	0	0	0	0	31.1
47	10-115	0.1	2	9	11	12	0	0	0	0	0	34.1
48	15-120	0.2	2.4	5	6.6	10.8	2.3	4.8	0	0	0	32.1

Case 3-1 Road with side market

					With PCU factor							
					Morning peak							
		0.1	0.4	1.0	1.1	1.2	2.3	4.8	1.8	3.2	6.0	
No	T.interval	M.bycicle	auto-rikshaw	auto(car)	Pick-up(4WD)	Mini-bus	Medium bus	Large bus	LCV	H. Truck	Truck.trailer	TOTAL
1	0-5'	0.0	3.2	2	1.1	7.2	2.3	9.6	1.8	6.4	0.0	33.6
2	5-10'	0.0	3.6	1	1.1	1.2	4.6	4.8	1.8	0.0	0.0	19.0
3	10-15'	0.0	4.4	1	0	2.4	0.0	4.8	3.6	0	0.0	16.2
4	15-20'	0.0	2.8	1	1.1	3.6	0.0	4.8	0.0	0	0.0	13.3
5	20-25'	0.0	4.8	1	1.1	3.6	0.0	0.0	0.0	3.2	0.0	13.7
6	25-30'	0.0	1.6	1	2.2	6.0	0.0	0.0	0.0	0	0.0	10.8
7	30-35'	0.1	7.2	2	1.1	1.2	0.0	4.8	3.6	0	0.0	20.0
8	35-40'	0.1	7.2	4	6.6	1.2	0.0	0.0	0.0	0	0.0	20.0
9	40-45'	0.2	6.0	7	5.5	2.4	0.0	4.8	5.4	0	0.0	31.3
10	45-50'	0.1	9.2	6	4.4	3.6	0.0	4.8	5.4	0	0.0	33.5
11	50-55'	0.1	7.6	6	4.4	3.6	0.0	4.8	0.0	0	0.0	26.5
12	55-60'	0.1	8.0	0	4.4	2.4	2.3	0.0	3.6	0	0.0	21.7
13	60-65'	0.2	8.8	3	4.4	0.0	0.0	0.0	3.6	3.2	0.0	24.1
14	65-70'	0.0	1.6	1	0	0.0	0.0	0.0	3.6	6.4	0.0	12.6
15	70-75'	0.2	5.2	6	6.6	0.0	0.0	4.8	1.8	0	0.0	24.6
16	75-80'	0.3	6.0	3	3.3	2.4	0.0	0.0	1.8	0	0.0	16.8
17	80-85'	0.0	6.8	7	9.9	2.4	2.3	0.0	1.8	3.2	0.0	35.2
18	85-90'	0.2	6.8	5	5.5	3.6	0.0	0.0	1.8	0	0.0	23.8
19	90-95'	0.2	10.8	4	5.5	1.2	0.0	0.0	0.0	3.2	0.0	27.6
20	95-100'	0.3	8.0	6	8.8	1.2	4.6	0.0	0.0	0	0.0	29.8
21	100-105'	0.3	8.0	3	11	0.0	4.6	0.0	0.0	0	0.0	27.8
22	105-110'	0.0	8.0	3	3.3	0.0	4.6	0.0	0.0	0	0.0	18.9
23	110-115'	0.2	5.6	6	3.3	0.0	2.3	0.0	0.0	0	0.0	17.4
24	115-120'	0.2	4.0	5	2.2	1.2	2.3	0.0	1.8	0	0.0	16.7
					Evening peak							
25	0-5'	0	6.4	4	1.1	2.4	0	0	0	3.2	0	17.1
26	5-10'	0	6.4	3	1.1	3.6	2.3	0	0	0	0	17.3
27	10-15'	0	3.6	2	0	4.8	0	0	0	0	0	11.3
28	15-20'	0.1	6.8	3	1.1	1.2	4.6	0	0	0	0	16.8
29	20-25'	0.2	7.6	0	2.2	3.6	0	0	0	0	0	13.6
30	25-30'	0.2	7.6	2	2.2	3.6	0	0	0	0	0	15.6
31	30-35'	0	4	3	2.2	0	0	0	0	6.4	0	16.5
32	35-40'	0.2	7.2	4	0	0	0	0	1.8	0	0	15.0
33	40-45'	0.1	4.4	6	0	2.4	0	0	0	3.2	0	16.1
34	45-50'	0.2	4	5	0	2.4	0	0	0	0	0	12.5
35	50-55'	0.1	6	3	2.2	6	2.3	0	0	0	0	19.6
36	55-60'	0	4.4	6	2.2	6	0	4.8	0	3.2	0	27.5
37	60-65'	0	9.6	3	0	2.4	2.3	0	0	0	0	19.1
38	65-70'	0.1	7.2	5	2.2	4.8	4.6	0	0	0	0	23.9
39	70-75'	0.2	8	4	2.2	3.6	0	0	0	3.2	0	21.2
40	75-80'	0	6.4	5	6.6	1.2	0	0	3.6	0	0	22.8
41	80-85'	0.1	5.6	3	6.6	4.8	0	0	0	0	0	20.1
42	85-90'	0.3	6.8	3	5.5	1.2	0	0	1.8	0	0	19.5
43	90-95'	0.2	7.2	3	6.6	2.4	0	0	0	3.2	0	24.4
44	95-100'	0	8	6	5.5	1.2	0	0	0	3.2	0	24.8
45	100-105'	0.3	7.2	3	2.2	2.4	2.3	0	1.8	0	0	20.1
46	105-110'	0	8	3	3.3	0	4.6	0	0	0	0	18.9
47	110-115'	0.3	4.8	6	7.7	2.4	2.3	0	0	0	0	23.5
48	115-120'	0.2	4	7	1.1	2.4	2.3	0	3.6	0	0	20.6

Case 3-2 Road without side market

						With PCU Factor						
						Morning peak						
		0.1	0.4	1.0	1.1	1.2	2.3	4.8	1.8	3.2	6.0	
No	T.interval	M.bycicle	auto-rikshaw	auto(car)	Pick-up(4WD)	Mini-bus	Medium bus	Large bus	LCV	H. Truck	Truck.trauler	TOTAL
1	0-5'	0.1	4.0	10	5.5	8.4	6.4	4.8	5.4	6.4	0.0	51.0
2	5-10'	0.3	6.8	3	6.6	21.6	0.0	0.0	3.6	0.0	0.0	42.8
3	10-15'	0.1	8.4	3	6.6	18.0	3.2	14.4	1.8	0	0.0	55.5
4	15-20'	0.2	7.2	3	8.8	16.8	0.0	9.6	0.0	0	0.0	46.5
5	20-25'	0.4	8.4	7	9.9	18.0	0.0	0.0	0.0	3.2	0.0	46.9
6	25-30'	0.4	8.0	8	8.8	24.0	3.2	9.6	0.0	0	0.0	62.9
7	30-35'	0.5	9.2	10	12.1	24.0	0.0	4.8	3.6	0	0.0	64.2
8	35-40'	0.4	8.0	6	7.7	20.4	0.0	0.0	3.6	0	0.0	47.0
9	40-45'	0.3	8.0	9	8.8	21.6	0.0	0.0	0.0	3.2	0.0	51.8
10	45-50'	0.3	6.4	11	13.2	27.6	3.2	0.0	7.2	0	0.0	69.8
11	50-55'	0.2	10.0	7	8.8	21.6	3.2	0.0	3.6	3.2	0.0	57.6
12	55-60'	0.3	7.2	8	11	15.6	3.2	4.8	1.8	0	0.0	51.9
13	60-65'	0.3	9.2	4	3.3	21.6	0.0	0.0	0.0	6.4	0.0	44.8
14	65-70'	0.1	5.6	3	3.3	13.2	0.0	0.0	1.8	6.4	0.0	34.3
15	70-75'	0.3	7.6	4	12.1	10.8	0.0	0.0	3.6	0	0.0	38.4
16	75-80'	0.0	6.0	4	3.3	19.2	0.0	0.0	1.8	0	0.0	34.3
17	80-85'	0.2	4.8	7	4.4	16.8	3.2	0.0	1.8	0	0.0	38.2
18	85-90'	0.3	9.2	5	8.8	26.4	0.0	0.0	3.6	0	0.0	53.3
19	90-95'	0.3	6.0	8	8.8	16.8	0.0	0.0	0.0	0	0.0	39.9
20	95-100'	0.3	12.4	6	7.7	15.6	0.0	0.0	0.0	3.2	0.0	45.2
21	100-105'	0.3	10.4	6	4.4	20.4	0.0	0.0	1.8	0	0.0	43.3
22	105-110'	0.0	8.0	3	3.3	22.8	6.4	0.0	0.0	0	0.0	44.4
23	110-115'	0.2	9.2	6	3.3	19.2	3.2	0.0	1.8	3.2	0.0	46.1
24	115-120'	0.1	6.8	5	2.2	16.8	3.2	0.0	1.8	0	0.0	35.9
						Evening peak						
25	0-5'	0.6	8	7	5.5	13.2	0	0	1.8	3.2	6	45.3
26	5-10'	0.1	9.2	1	3.3	10.8	0	4.8	5.4	0	0	34.6
27	10-15'	0.1	7.6	5	7.7	13.2	0	0	12.6	3.2	0	50.3
28	15-20'	0	8	7	4.4	13.2	0	0	1.8	9.6	0	44.9
29	20-25'	0	10.4	3	9.9	14.4	2.3	4.8	0	0	6	50.8
30	25-30'	0	13.2	6	4.4	18	2.3	0	3.6	3.2	0	50.7
31	30-35'	0	7.2	3	9.9	14.4	4.6	4.8	5.4	0	0	50.2
32	35-40'	0.3	7.2	7	1.1	15.6	0	4.8	5.4	3.2	0	44.6
33	40-45'	0.1	6	1	1.1	15.6	2.3	0	0	0	0	26.1
34	45-50'	0.2	12	5	5.5	14.4	0	0	3.6	0	0	41.6
35	50-55'	0.3	6.8	4	6.6	21.6	2.3	0	9	0	0	50.6
36	55-60'	0.2	7.6	6	1.1	13.2	0	0	0	0	0	28.1
37	60-65'	0.2	9.6	1	5.5	24	0	0	3.6	3.2	0	47.1
38	65-70'	0.2	7.6	4	2.2	21.6	0	0	1.8	3.2	0	40.6
39	70-75'	0.4	14.8	7	9.9	26.4	0	0	1.8	0	0	60.3
40	75-80'	0.3	7.2	5	4.4	19.2	0	0	1.8	3.2	0	42.0
41	80-85'	0	7.2	4	6.6	22.8	0	0	1.8	3.2	0	45.6
42	85-90'	0	9.2	3	5.5	18	2.3	0	3.6	6.4	6	54.0
43	90-95'	0.2	10.8	4	5.5	15.6	0	4.8	1.8	0	0	42.7
44	95-100'	0.2	5.6	5	8.8	22.8	0	14.4	3.6	3.2	0	63.6
45	100-105'	0.1	7.2	5	4.4	19.2	0	0	0	0	0	35.9
46	105-110'	0.2	7.6	4	6.6	16.8	0	4.8	1.8	9.6	0	51.4
47	110-115'	0.3	6	3	6.6	20.4	2.3	0	7.2	3.2	0	49.0
48	115-120'	0.1	6.4	2	5.5	15.6	2.3	0	3.6	3.2	0	38.7

APPENDEX-III: ANOVA Test

Case 1-1 Road with structural median

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.775063358							
R Square	0.600723208							
Adjusted R Square	0.592043278							
Standard Error	2.371788238							
Observations	48							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	389.3229426	389.3229426	69.2083	1.0054E-10			
Residual	46	258.7674546	5.625379448					
Total	47	648.0903972						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	30.74149166	0.923241934	33.29733034	7.64E-34	28.88310203	32.5998813	29.19168197	32.29130135
density(veh/km)	-3.221199902	0.38720289	-8.319152538	1.01E-10	-4.000598895	-2.4418009	-3.871182065	-2.571217739

Case 1-2 Road without structural median

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.879205664							
R Square	0.7730026							
Adjusted R Squar	0.768067874							
Standard Error	1.424572931							
Observations	48							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	317.8976215	317.8976215	156.6455	2.0416E-16			
Residual	46	93.35276962	2.029408035					
Total	47	411.2503911						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	29.93432292	0.756934807	39.54676496	3.64E-37	28.41069218	31.45795367	28.66368643	31.20495942
density(veh/km)	-2.474037769	0.197673009	-12.51580971	2.04E-16	-2.8719329	-2.076142639	-2.80586362	-2.142211914

Case 2-1 Rod with foot path

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.842012586							
R Square	0.708985194							
Adjusted R Squ	0.702658786							
Standard Error	2.271054165							
Observations	48							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	578.009395	578.0094	112.0676	6.44597E-14			
Residual	46	237.2536029	5.157687					
Total	47	815.2629979						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	39.84769764	1.307210924	30.48299	3.74E-32	37.21641852	42.47897675	37.65333441	42.04206087
density(veh/km	-6.55891109	0.619572007	-10.5862	6.45E-14	-7.80604486	-5.31177733	-7.598962092	-5.51886009

Case 2-2 Rod without foot path

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.861263							
R Square	0.741774							
Adjusted R Squar	0.736161							
Standard Error	2.021471							
Observations	48							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	539.9641576	539.9642	132.1387	4.03607E-15			
Residual	46	187.9718263	4.086344					
Total	47	727.9359839						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	36.99606	1.167194092	31.69658	6.72E-33	34.64662479	39.3455045	35.03674212	38.95538715
density(veh/km/	-5.49605	0.478118379	-11.4952	4.04E-15	-6.45844941	-4.53364465	-6.298645426	-4.69344863

Case 3-1 Road with road-side activity

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.777414							
R Square	0.604373							
Adjusted R Squa	0.595773							
Standard Error	1.786158							
Observations	48							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	224.1904933	224.1905	70.27121	8.11664E-11			
Residual	46	146.7565762	3.19036					
Total	47	370.9470696						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	37.85965	1.162513334	32.56706	2.03E-33	35.51962841	40.19966435	35.9081813	39.81111149
density(veh/km	-5.8593	0.698967896	-8.38279	8.12E-11	-7.266252376	-4.452353573	-7.0326327	-4.68597324

Case 3-2 Road without side market

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.736704501							
R Square	0.542733522							
Adjusted R Squa	0.532572044							
Standard Error	2.626546298							
Observations	47							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	368.468118	368.4681	53.41089	3.56419E-09			
Residual	45	310.4435454	6.898745					
Total	46	678.9116635						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 90.0%*	*pper 90.0%*
Intercept	29.09585394	0.919638511	31.63836	2.19E-32	27.2436069	30.9481	27.55139	30.64032
density(veh/km	-6.542810563	0.895260552	-7.30828	3.56E-09	-8.345957874	-4.73966	-8.04634	-5.03929

APPENDEX IV: t-Distribution

Table F The *t* Distribution

d.f.	Confidence intervals	80%	90%	95%	98%	99%
	One tail, α	0.10	0.05	0.025	0.01	0.005
	Two tails, α	0.20	0.10	0.05	0.02	0.01
1		3.078	6.314	12.706	31.821	63.657
2		1.886	2.920	4.303	6.965	9.925
3		1.638	2.353	3.182	4.541	5.841
4		1.533	2.132	2.776	3.747	4.604
5		1.476	2.015	2.571	3.365	4.032
6		1.440	1.943	2.447	3.143	3.707
7		1.415	1.895	2.365	2.998	3.499
8		1.397	1.860	2.306	2.896	3.355
9		1.383	1.833	2.262	2.821	3.250
10		1.372	1.812	2.228	2.764	3.169
11		1.363	1.796	2.201	2.718	3.106
12		1.356	1.782	2.179	2.681	3.055
13		1.350	1.771	2.160	2.650	3.012
14		1.345	1.761	2.145	2.624	2.977
15		1.341	1.753	2.131	2.602	2.947
16		1.337	1.746	2.120	2.583	2.921
17		1.333	1.740	2.110	2.567	2.898
18		1.330	1.734	2.101	2.552	2.878
19		1.328	1.729	2.093	2.539	2.861
20		1.325	1.725	2.086	2.528	2.845
21		1.323	1.721	2.080	2.518	2.831
22		1.321	1.717	2.074	2.508	2.819
23		1.319	1.714	2.069	2.500	2.807
24		1.318	1.711	2.064	2.492	2.797
25		1.316	1.708	2.060	2.485	2.787
26		1.315	1.706	2.056	2.479	2.779
27		1.314	1.703	2.052	2.473	2.771
28		1.313	1.701	2.048	2.467	2.763