ADDISS ABBA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GRADUATE STUDIES

ASSESSING CONSISTENCY OF PCE VALUES ON HCM 2010 FOR SELECTED MULTILANE HIGHWAYS OF ADDIS ABABA, ETHIOPIA

A Thesis submitted to school of civil and environmental engineering of Addis Ababa institute of technology in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Road and Transport Engineering)

By: Eaden Haile

Main Advisor: Dr. Robeam Solomon (PhD)

Co- Advisor: Tamiru Tilahun (MSc)

October 2023

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Graduate Studies

ASSESSING CONSISTENCY OF PCE VALUES ON HCM 2010 FOR SELECTED MULTILANE HIGHWAYS OF ADDIS ABABA, ETHIOPIA

By: Eaden Haile

A Thesis submitted to school of civil and environmental engineering of Addis Ababa institute of technology in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Road and Transport Engineering)

Approved by Board of Examinations:

______________________	______________________	______________________
Advisor	Signature	Date
______________________	______________________	______________________
Internal Examiner	Signature	Date
______________________	______________________	______________________
External Examiner	Signature	Date
______________________	______________________	______________________
Chairman	Signature	Date

DECLARATION

I hereby declare that this research paper, titled "Accessing Consistency of PCE values in HCM 2010 for selected multilane highways of Addis Ababa, Ethiopia" is my original work. The work has not been presented elsewhere for assessment and award of any degree or diploma. I affirm that all sources utilized in this paper have been appropriately cited and acknowledged.

Name: Eaden Haile

Signature: ____________________

Place: Addis Ababa University

Addis Ababa Institute of Technology

School of civil and environmental engineering

Graduate studies

Road and transport engineering

Date: October 2023

Acknowledgement

I would like to express my sincere gratitude to my family for their invaluable support and assistance throughout the process of conducting this research paper. Their guidance in collecting field data has been immensely helpful.

I would also like to extend my deepest appreciation to my advisor, Dr. Robeam Solomon, for his kind and critical advice and suggestions from the initial proposal stage to the completion of this paper.

Furthermore, I would like to acknowledge the staff members of Addis Ababa City Roads Administration and Addis Ababa Transport Management Agency, particularly Mr. Abel, for providing me with the PTV VISSIM software and arranging a conducive work environment. Their support has been instrumental, and I am truly grateful.

Lastly, I am indebted to Addis Ababa University for granting me the opportunity to pursue my MSc. in road and transport engineering through a full scholarship. Their generosity and belief in my potential have been invaluable.

ABSTRACT

Passenger Car Equivalents (PCE) plays a crucial role in road design and traffic management by converting the impact of various vehicle categories on a traffic stream into a standardized equivalent passenger car. Their utilization is essential in a heterogeneous vehicle composition in road traffic. Hence, main objective of this research is to assess the consistency of PCE values in the Highway Capacity Manual (HCM, 2010) for local multilane highways.

To achieve the stated objective, three key parameters were considered. Firstly, the assumptions made in HCM 2010 were comprehensively reviewed and compared with the actual local conditions. Secondly, existing relevant literature was surveyed to gather insights from other similar studies. Lastly, data was collected from the Outer Ring Road, a selected multilane highway in Addis Ababa and local PCE values were determined using the flow rate and density method, the speed area method, and simulation with Planung Transport Verkehr AG Verkehr In Städten – Simulations Modell version 9 (PTV VISSIM).

The analysis revealed that the direct use of PCE values presented in HCM 2010 is inconsistent with the local conditions. Consequently, the study proposes different PCE values for various vehicle categories and heavy vehicles in general, taking into account the road's percent grade and the proportion of heavy vehicles in the traffic stream. The findings show that, proposed PCE values significantly deviate from those in HCM 2010 due to the variations observed in the local condition.

In conclusion, this study underscores the inconsistency of directly applying PCE values from HCM 2010 in road design and traffic management projects. Accordingly, using small values of PCE leads to underestimating traffic volume, underestimating traffic impact, designing inefficient road pavements, and inaccurately analyzing and estimating costs. Hence, the study advocates for the use of local PCE values derived from researches which consider the specific local conditions.

Keywords: Passenger Car Equivalents; Multilane Highway; Heavy Vehicles; HCM 2010.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AACRA – Addis Ababa City Roads Authority

AATB – Addis Ababa Transport Bureau

AATMB – Addis Ababa Transport Management Bureau

ERA – Ethiopian Roads Administration

HCM – Highway Capacity Manual

Km/hr – Kilometer per hour

LOS – Level of Service

LT- Light Trucks

MT – Medium Trucks

PCE – Passenger Car Equivalents

Pc/hr – Passenger car per hour

TRB – Transport Research Board

Veh/hr – Vehicle per hour

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

In most developing countries the traffic composition is heterogeneous, composed of different types of vehicles. In Ethiopia, the road traffic is composed of a variety of vehicles which share the same route at the same time. As per the report by the Ministry of Transport in 2020 as cited by Yonas (2020), the number of registered vehicles in Ethiopia has reached 1,200,110, of which nearly 52.5% i.e. 630,440 vehicles are registered in Addis Ababa. As there are no restrictions set to alter the movement of heavy vehicles in the capital and due to the rapid economic development of the city, various types of vehicles are present and seen in the road networks. Hence, to analyze such a variety of vehicles, Passenger Car Equivalency (PCE) is used.

Since its introduction in the 1965 Highway Capacity Manual (HCM, 1965) different researches have been conducted to determine PCE values in their respective local conditions. PCE values in HCM are determined based on vehicle characteristics, traffic composition, roadway network and condition in the United States of America, mainly, that computing PCE values with respect to local conditions becomes the concern of many researchers.

Most of the research conducted previously indicates that directly adopting PCE values in HCM in countries other than the USA leads to inappropriate design and analysis of road traffic, as the local characteristics and parameters were different with respect to HCM considerations. Cunagin and Messer (1983) have calculated the PCE values using the concept in HCM 1965 based on the relative delay method. In their research, they have found PCE values which are different from HCM 1965. Other researches by Tanaboriboon and Aryal (1990), Ahmed, A., Younghan, J., and Hesham, R. (2005), Partha, S., Quazi, S., HOSSAIN, H., M. Iqbal, M., MD. Zahurul, I. (2009) etc. computed and determined PCE values which are compatible with their local conditions.

In determining PCE values, different sections or nodes of a roadway segment like signalized intersections, freeways, two lane two way roads, multilane highways etc. could be emphasized.

In Ethiopia, few researches were conducted aiming to determine the local PCE values. Among those few researches, most of them were conducted at different signalized intersections and quite few on roadway segments. But, few researches have been conducted in determining local PCE values in multilane highways. Therefore, this research aims in assessing consistency of PCE values in HCM 2010 and determining local PCE values in selected multilane highway (Arterials) of Addis Ababa.

1.2 Statement of the Problem

In the capacity analysis and level of service determination of roads with heterogeneous road traffic streams, PCE values play an important role in changing diverse vehicle types to equivalent passenger cars which have the same effect on the traffic flow. Furthermore, PCE serves as a valuable tool for transportation planners and engineers, assisting in the efficient allocation of road resources and the planning of infrastructure projects; for Traffic Managers in effectively managing traffic congestion and enhancing traffic flow and for designers to accurately calculate the investment needed for road infrastructures capable of accommodating a diverse range of vehicle types. With this regard, HCM 2010 presented PCE values that are available to be used for determining capacity and LOS.

In Ethiopia, like most other developing countries, PCE values which are stated on HCM are being used in quality assessment of multilane highways and other road types and intersections. As HCM is developed in the United States of America direct application of PCE values needs to be assessed due to significant differences in local conditions of other countries. HCM 2010 states that:

> *HCM users are cautioned, however, that the majority of the research base, the default values, and the typical applications are from North America, particularly from the United States. Although there is considerable value in the general methods presented, their use outside of North America requires additional emphasis on calibrating the equations and the procedures to local conditions.* (HCM, 2010. HCM User’s Guide, Page 1-6)

Several studies have examined the applicability of PCE values from the HCM to local conditions in different sections and intersections of roads at international level. However, in Ethiopia, there has been limited research conducted on this topic, with most studies focusing on signalized intersections and some on other road segments, such as the Addis Adama Expressway (Girum, 2016), selected trunk roads (Ararsa, 2020) and multilane highways (Addisu, 2021). Consequently, It is crucial to determine specific PCE values for different road segments, as various parameters, such as road geometry, control conditions, and vehicle characteristics (including dimensions and speeds), can significantly influence PCE values.

Accordingly, as the construction of multilane highways continues to increase significantly due to the country's rapid economic growth, it becomes important to have accurate local PCE values for proper design and management of these highways. Although Addisu (2021) conducted research on multilane highways in Addis Ababa, it only considered level terrain and overlooked the influence of various heavy vehicle compositions on the PCE value. Therefore, this research aims to address this gap by assessing the consistency of PCE values in the HCM 2010 and indicate local PCE values that account for different road gradients and proportions of heavy vehicles.

1.3 Research Questions

1. What are the contributing factors in determining PCE of vehicles on multilane highways?
2. How much does PCE values from HCM 2010 deviate from local PCE values?

1.4 Research Objectives

1.4.1 General Objective

The primary aim of this research is to evaluate the reliability of PCE values for heavy vehicles according to the HCM 2010 utilizing the flow rate and Density method of analysis, focusing on selected multilane highway (arterial) located in Addis Ababa, Ethiopia.

1.4.2 Specific Objectives

- Identifying if PCE values in HCM 2010 are consistent for local conditions of multilane highways of Addis Ababa

- Calibrating and validating outputs of PTV Vissim which will be used as an alternative way to determine PCE values
- Determining variation of PCE values with different methods of analysis

1.5 Significance of the Research

In the world of road construction and management, there is a critical need for accurate PCE values to ensure efficient decision-making and cost-effective policies. While research has been conducted internationally to determine these values, there exists a significant literature gap in Ethiopia. This is surprising considering that a massive 61 billion birr was allocated to road construction in the country's fiscal year 2020/2021, accounting for 12.82% of the total budget. With such extensive investments, it becomes imperative to establish precise PCE values that not only help manage roads effectively but also contribute to reducing fuel consumption, air pollution, and road user costs associated with proposed changes. Furthermore, out of the 1090.11Km road network in Ethiopia's capital city, a staggering 357.43Km, or 32.8%, consists of Primary Arterial Streets (AACRA, 2020), making it an essential road class. Hence, this research aims to fill the gap by determining local PCE values for multilane highways and could potentially guide traffic analysis and decision-making processes within the local context. Additionally, it will serve as a valuable reference for future researchers investigating various levels of service and climatic conditions to further enhance the understanding of road management in Ethiopia.

1.6 Scope of the Study

The research is conducted on a selected multilane highway located in Addis Ababa. It stretches from Goro-Tulu Dimtu, which is 14.3km, and Haile Garment to Tulu Dimtu which is 15.3 km.

1.7 Limitations of the Study

The research is limited in covering all rural and sub-urban multilane highways of Addis Ababa due to time and money constraints. Furthermore, the research is limited in that it only considers clear weather conditions for the analysis.

1.8 Organization of the Study

This research is comprised of five chapters. The first chapter provides an introduction to the study, including background information, a statement of the problem, objectives of the study, and other subsections that offer further insight into the research. The second chapter presents a review of various literatures and publications. It aims to summarize local and international research conducted on determining PCE and literatures related to passenger car equivalents and multilane highways. The third chapter presents the methodology used in conducting this study. This chapter includes a brief discussion of site selection, the method of investigation, and the calibration and validation of the PTV Vissim software, which was one of the methods used in the investigation. The fourth chapter discusses the findings of the study. In this chapter, the research findings are discussed in detail for every scenario. The final chapter incorporates the conclusion and recommendations derived from the research findings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Multilane Highways

Multi-lane highways are those roads with two or more lanes in each direction. They are most of the time situated in rural areas to connect two or more towns, rural centers, or business areas where the traffic volume is very high.

HCM 2010 defines Multilane Highways as “highways that do not have full control of access and that have two or more lanes in each direction, with traffic signals or roundabouts spaced at least 2 mi apart on average”. Multilane highways have a significant advantage in ensuring smooth traffic operation and providing good capacity with a considerable good level of service.

2.1.1 Types of Multilane Highways

According to HCM 2010, multilane highways were classified into four categories based on the type of median introduced to separate the opposite traffic flows. These are:

1. Divided Suburban Multilane Highway

Divided Suburban Multilane Highway are those multilane highways situated in sub-urban areas having a median that separates the opposite traffic. The median could be designed to provide a safe distance for vehicles that left the carriageway to decrease their speed safely; and could be left for future expansion.

2. Undivided Suburban Multilane Highway

These are similar to divided suburban multilane highways situated in sub-urban but different from the divided suburban by not having a median.

3. Suburban Multilane Highway With Two Way Left Turn Lanes (TWLTL)

These types of multilane highways are different in that the central lane serves as a lane changing lane for left turning vehicles coming from each direction of the highway. Such types of lanes are very important for driveways with limited space, and have the advantage of reducing accident rate.

4. Undivided Rural Multilane Highway

Undivided Rural Multilane Highway are one type of multilane highways which are located in rural areas with a considerable high traffic volume. These types of multilane highways have no median due to restricted right of way and/or unfavorable terrain conditions.

On the other hand, Addis Ababa City Roads Authority design manual (AACRA 2004) categorizes multilane highways as Arterial and Sub-Arterial Roads. Arterial and Sub-Arterial roads always contain a median which is used to provide space for pedestrian crossing, left turn lens, utility line passage, landscaping planting, road furniture, and also for future expansion.

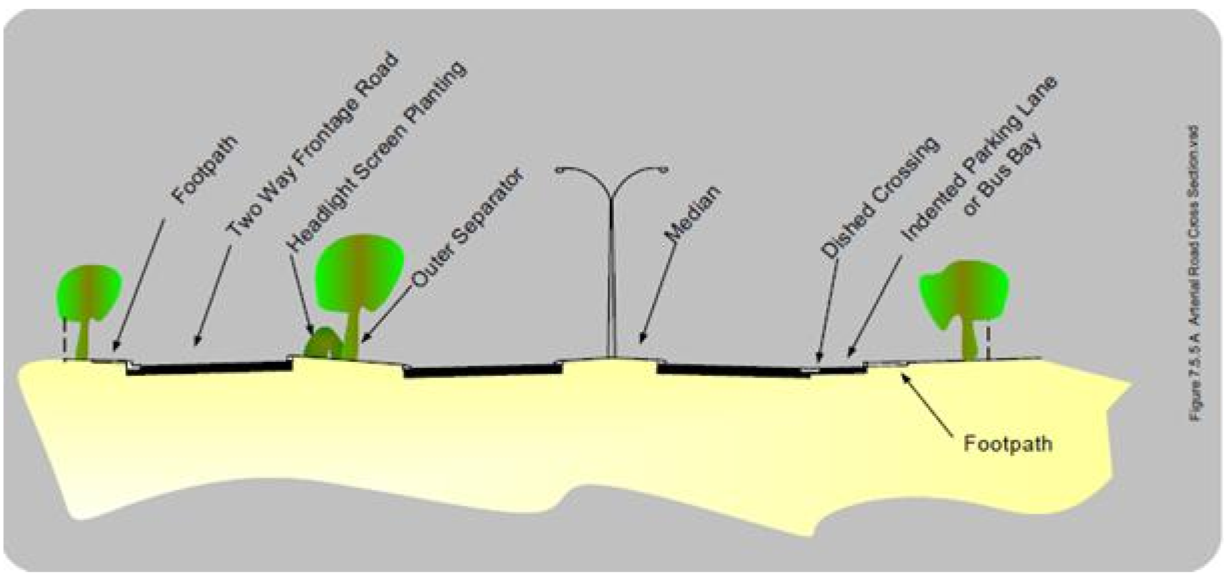


Figure 2.1: Arterial Road/Sub Arterial Cross Section (source: AACRA (2004), geometric design manual, page 7-17)

2.2 Passenger Car Equivalents (PCEs)

Passenger car equivalents, also called passenger car units are factors used to consider the effect of heavy vehicles in the traffic stream. HCM 2010 defines PCE as “the number of passenger cars that would use the same amount of freeway capacity as one truck, bus, or RV under the prevailing conditions".

PCEs were first introduced in the 1965 HCM, in order to analyze Highway streams with heterogeneous traffic conditions. In fact, most highway segments are composed of heterogeneous traffic conditions unless restriction is set for some vehicles. In determining the capacity and level of service of such types of highways, the use of PCE values becomes mandatory because it allows for proper consideration of the effect of heavy vehicles in the traffic stream relative to passenger cars.

Determination of PCE values for various road traffic characteristics has been the major concern of many researchers and scholars since the term was first introduced in the 1965 HCM. To this end, different researchers and scholars have proposed various methods of determining PCE values for different types of roads and road nodes like signalized intersections, considering different attributes of specific local conditions.

2.2.1 Importance of PCE values

PCE values are important for:

- traffic capacity analysis
- level of service measures
- signal design and coordination
- saturation flow rate determination
- development of traffic flow models
- traffic management

2.2.2 Factors Affecting PCEs

PCE values differ for different vehicle classes depending on many contributing factors. Al-Kaisy et al., (2002) and Anand et al., (1999) (as cited in Kanakabandi. S., and Brind. K., 2014) stated factors on which the value of PCE depends on. Some of the factors stated by Al-Kaisyet et al., (2002) are prevailing traffic condition, geometric condition of the road, and control conditions which are suited to facilitate the traffic flow, grade and length of grade, and the percentage of heavy vehicles. On the other hand, dimensions, power, speed, acceleration and braking characteristics of the vehicle, road characteristics, access controls, type of road, and presence and type of intersection are mentioned as major factors by Anand et al., (1999).

2.2.3 Methods Used to Determine PCE Values

As per different literature, there are six common methods used to determine PCE Values based on different parameters. These are:

A. PCEs Based on Flow Rates and Density

Flow rate is a rate at which a given number of vehicles pass a reference point on the roadway. And density is defined as the number of vehicles in a given length of roadway.

John and Glauz (1976) (as cited in Kanakabandi. S., and Brind. K., 2014) proposed a relationship to compute PCE values based on percentage of grade, mixed vehicle flow, and truck volume to capacity ratio:

$$PCE = \frac{q_B - q_M(1-p_T)}{P_T * q_M} \text{……………………….Equation 1}$$

Huber (1982) (as cited in Kanakabandi. S., and Brind. K., 2014) developed a formula for estimating PCE values in multilane and free flow conditions. The relationship that he proposed was:

$$PCE = \frac{1}{P_T}\left(\frac{q_B}{q_M} - 1\right) + 1 \text{……………………. Equation 2}$$

Where: q_B = equivalent passenger car only flow rate for a given v/c ratio,

q_M= mixed flow rate, and

P_T= truck proportion in the mixed traffic flow

The equivalent passenger car only flow rate is explained as a flow rate of the traffic stream as if all vehicles were passenger cars; mixed flow rate is a flow rate of the traffic stream when there is mixed vehicle categories.

André, L., and José, R. (2011) develop new PCE values for divided multilane highways in Brazil. They used traffic stream density to compute new PCE values. That is, the PCE values were computed by comparing base stream and mixed stream with the same density. The relationship they used to obtain new PCE values was the same as Huber's method. In their study, they develop PCE values by comparing base flow condition (traffic stream with only passenger cars) and mixed flow condition (traffic stream with both passenger cars and trucks). To consider various traffic and geometric conditions in the analysis, they used simulation software called CORSIM (version 5.1) which is calibrated by data collected from divided highways of Brazil. To study the characteristics of trucks, they collected gross vehicle weight, individual axle weight, nominal engine power, axle configuration and overall length of the trucks; which are then used to calibrate CORSIM software to local conditions. In the result of their research, they have provided PCE values on divided multilane highways with free flow speed (FFS) of 110km/hr and 100 km/hr having specific upgrades.

A research conducted by Girum, T. (2016) on basic freeway segments of Addis Ababa-Adama expressway have determined different values of PCE for trucks and buses. In his study, he has used flow rate and density method reasoning that HCM 2010's analysis is based on flow rates. The study concludes that the new PCE values for trucks and buses in freeways are different from PCE values on HCM 2010 because of variability in local conditions. The main limitation of the study was, the analysis is only done for a flow with level of service (LOS) A; other traffic flow conditions are not included

B. PCEs Based on modified density method

Tiwari et al. (2000) and Tiwari et al. (2007) (as cited in Ballari Syed. O., Pranab. K., and Mallikarjuna. C., 2019) uses density to calculate new PCE values for rural and suburban highways in India.

$$PCE_{truck} = \frac{K_{car}/W_L}{K_{trunck}/W_L} \quad \text{……………………} \textit{Equation 3}$$

Where, K_{car} = density of cars in the homogenous traffic stream

K_{truck} = density of trucks in the homogenous traffic stream

W_L = lane width of the lane in the homogenous traffic

C. PCEs Based on Headways

Determination of PCE values based on the headway method has been used for decades since its introduction by Greenshield in 1947. This method basically relays on time headway and space headway parameters of a traffic stream. Greenshields (1947) (as cited by Syed, O. 2020), proposed a relationship to compute PCE values based on headway (time or space).

PCEi= hi/hc……………………*Equation 4*

Where, PCE_i= PCE of vehicle class I, h_i = normal progress of vehicle class I and h_c = normal progress of traveler vehicles

According to Kanakabandi. S., and Brind. K., (2014), Parthia, S., H. M. Iqbal, M., DR. Quazi, S., & MD. Zahurul, I. (2009). etc. determination of PCEs based on headways method was used at signalized intersections However, there are some research conducted in multilane highways using this method.

Muhammad (2013) did a research in determining PCE values for heterogeneous traffic streams conducted for midblock urban arterials in Karachi, Pakistan. In his study, he uses four different methods of determining PCE values in order to compare the values to each other and with currently available PCE numbers.

One of the methods he used was time headway method "based on the notion that passenger cars following large vehicles may have higher headways compared to time headway between two successive passenger cars at saturated flow conditions". The formula he used to get new PCE values was:

$$PCE = \frac{(1-p)(h_{px}+h_{xp}-h_{pp})+(ph_{xx})}{h_{pp}}$$ ……………………….*Equation 5*

Where, p = percentage of trucks at mixed traffic stream

h_{xp} = mean headway time in seconds for vehicle x following passenger car

h_{px} = mean headway time in seconds for passenger car following vehicle x

h_{pp} = mean headway time in seconds for passenger car following passenger car

ph_{xx} = mean headway time in seconds for vehicle x following vehicle x

D. PCEs Based on Queue Discharge Flow

A research by Ahmed, A., Younghan, J., and Hesham, R. (2005) determines PCE values for freeways and multilane highways during congestion. The data used to conduct the research was adopted from another previous research. In their analysis, they used queue discharge flow (QDF) as the equivalency criterion in developing the congested PCE factors.

$$\text{PCE} = \frac{\text{(actual field capacity in pcph} - \text{number of PCs}}{\text{number of trucks}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 6}$$

where, pcph is passenger car per hour

To do this, simulation software, INTEGRATION, which was calibrated by the collected data and computed PCE values, was used. The researchers have finally found PCE factors taking the average of all PCE values from the total simulation runs. For validating the results of the simulation model, the researchers have used two data sets which were not used for the calibration process. The researchers have provided a set of PCE values for congested traffic conditions which was ‘roughly’ similar in format with PCE values provided in HCM.

E. PCEs Based on Speed- Area

A. Mehar, S. Chandra; and S. Velmurugan (2014) conducted a research on determining PCE values for various vehicles in interurban multilane highways of India at different levels of service (LOS). In their study, they have used speed and physical rectangular area of vehicles as criterion.

$$PCEi = \frac{V_c/V_i}{A_c/A_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 7}$$

Where, PCE_i = PCE value for vehicle type i

Vc = speed of standard vehicle

Vi = speed of i^{th} type of vehicle

Ac = physical rectangular area of standard car

Ai = physical rectangular area of i^{th} type of vehicles

To consider different traffic flow and speed characteristics, they use a microscopic traffic simulation model called PTV VISSIM. But before using the simulation model, they calibrated it with data which was not used for further analysis in the course of their research. The researchers have determined PCE values for different congestion levels and checked the outcome against the collected field data.

F. *PCEs Based on Regression method*

Regression methods have been used by scholars as an alternative method to determine PCEs. The relationship that they use might be linear or nob-linear, depending on the variables chosen to define the model.

In a research conducted by Eshetu, Z., and Mengistu, M., (2020), a multiple linear regression model was adopted to determine PCEs for different midblock sections of Hawassa City. In their empirical model the overall average stream speed was taken as the dependent variable and composition of each vehicle category were the independent variables.

$$Ust= U_f + C_1X_1+ C_2X_2 + C_3X_3+ .... CnXn \text{……………………. Equation 8}$$

Where: Ust = overall average stream speed of a day in km/hr.

U_f = Free flow speed

C_1 to Cn = Speed reduction coefficients

X_1 to Xn = Composition of each vehicle category

After having the model, PCEs were calculated taking the ratio of speed reduction coefficient for vehicle type i to is speed reduction coefficient for passenger cars, i.e.

$$PCEs= Ci/Cpc \text{…………………….Equation 9}$$

Another research by Helen, H. (2020) reveals that regression models can generate a good estimation of PCEs. In her research, the dependent variable was PCEs and the independent variable was traffic volume.

$$PCEs = a + b(10^{-x})Q, \quad \text{……………………….Equation 10}$$

Where; a=constant, y intercept

b=coefficient, and

Q=traffic volume in veh/hr

To model the above empirical relationship, PCEs determined using Speed-Area method was used. Validation of the model in predicting future values were examined using Adjusted R^2.

2.3. PTV VISSIM in Traffic Analysis and PCE Determination

There are numbers of traffic simulation software used to traffic analysis and determination of PCE values, such as PTV VISSIM, CORSIM, and TransModeler. Among these widely used traffic simulation software, PTV VISSIM is widely used by researchers and institutions in Ethiopia.

PTV VISSIM is a microscopic traffic simulation software which takes into account individual vehicle behaviour, vehicle type and category, driver behaviour and traffic interaction. The software is used for traffic emissions modeling, micro, meso or hybrid simulation, intelligent traffic control, simulation of autonomous and connected vehicles and prioritization of public transport.

Many scholars utilize PTV Vissim for determining PCE values. A research by Arpan, M., S. Chandra, and S. Velmurugan (2014) PTV VISSIM were used to generate the traffic flow and speed data which were difficult to obtain from field observation. The research was conducted on multilane interurban highways of India. After calibrating the software, they use speed area method to generate new PCE values. Zhou, J., Rilett, L., & Jones, E. (2019) conducted research on I-80 in western Nebraska, hypothesizing that PCE values from HCM-6 were not suitable for the western United States. In their study, they employed an equivalency capacity methodology and simulation with PTV Vissim-9. After completing their research, they discovered that the PCE values recommended in HCM-6 underestimate the impact of trucks on four-lane level freeway segments with high truck percentages. Another research by Addisu, T. (2021) utilizes PTV VISSIM simulation software in determining PCE values. The research was conducted in selected multilane highways of Addis Ababa, Ethiopia. In his research he uses speed area method to determine PCE values using the outputs of the software. A. Mehar, S. Chandra; and S. Velmurugan (2014), Pajecki, R., Ahmed, F., Qu, X. et al (2019), and other researchers also uses PTV Vissim to determine PCE values.

2.4. Vehicle Classification

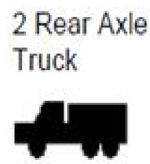
In Ethiopia, there are two road design manuals; Ethiopian Roads Administration (ERA) design manual and Addis Ababa City Roads Authority (AACRA) design manual. These manuals present different vehicle classification systems. The two vehicle classification systems are presented below:

Table 2.1: ERA's vehicle classification (Source: ERA 2013, flexible pavement design manual, page 2-3)

Class	Type	Axles	Description
1	Car	2	Passenger cars and taxis
2	Pick-up/ 4-wheel drive	2	Pick-up, minibus, land rovers, land cruisers
3	Small bus	2	<=27 seats
4	Bus/coach	2	>27 seats
5	Small truck	2	<=3.5 tones
6	Medium truck	2 or 3	3.5-7.5 tones
7	Large 2-axled truck	2	>7.5 tones
8	3-axled truck	3	>7.5 tones
9	4-axled truck	4	*
10	5-axled truck	5	*
11	6-axled truck	6	*
12	2-axled trailer	2	*
13	3-axled trailer	3	*

*Not needed for definition

Table 2.2: AACRA's vehicle classification (source: AACRA 2004, pavement design manual, section 6 page 2-3)

Category	**Cars**	**Light Trucks**	**Medium Trucks**	**Heavy Trucks**	**Articulated**
Axles	2	2	3	4	>4
Tires	4	6	10	14	>14
Length	< 3m	3m – 7.5m	3m – 7.5m	>7.5m	>7.5m
GVW	<3.5T	3.5T – 12T	>12T	>12T	>12T
Includes					

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

In this study, the outer ring road section of Addis Ababa which stretches from Hailegarment to Tulu Dimtu to Goro is selected. Haile Garment is located in $8^{0}56'13.9''$N and $38^{0}44'05.5''$E; Tulu Dimtu in 8.87^{0}N and 38.82^{0} E and Goro in $8^{0}58'44''$N and $38^{0}46'25''$E.

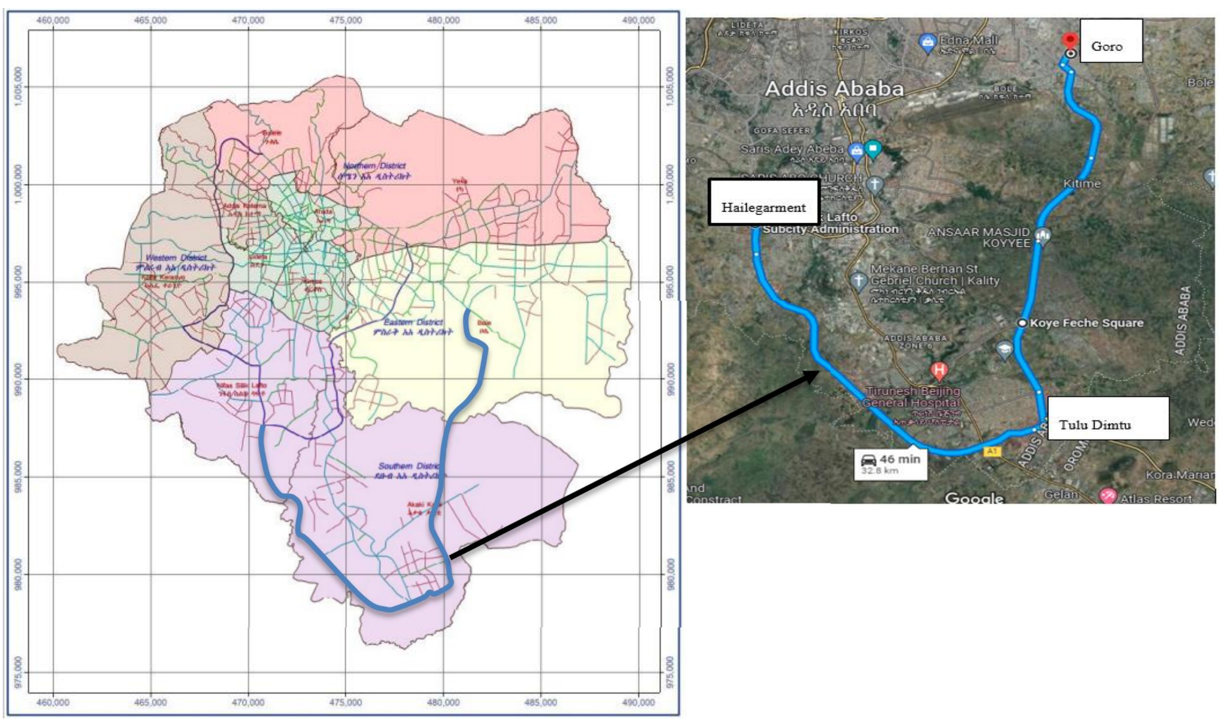


Figure 3.1: Route map from Haile Garment to Tulu Dimtu to Goro (Source: AACRA, (2020) and Google Map)

3.1.2 Site Selection

The study area was chosen due to different criterions and pilot discussions with transport professionals from AATB, AATMB and AACRA. The following points were major reasons for selecting this multilane highway as a study area.

- Its significance as a major route for heavy vehicles traveling to and from Addis Ababa.
- Additionally, it serves as a primary route for drivers traveling to various destinations within the country, and Djibouti, next to the Addis-Adama Expressway.
- Furthermore, the presence of condominium houses in Gelan, Tulu Dimtu Square, and Koye Feche contributes to the area's high volume of passenger cars used by residents.

Despite having heterogeneous traffic conditions, the selected road segment is multilane highway which satisfies most of the requirements set in HCM 2010 for analysis of multilane highways.

Table 3.1. Requirements of HCM 2010 for multilane roads and characteristics of the selected road

Criteria	HCM 2010	Selected Road
Number of lanes	four to six lanes (in both directions)	Six lanes(in both directions)
Traffic volume	15,000 to 40,000 veh/day	>20,000 veh/day
Posted speed limit	Between 40 and 55 mi/h. (64.37km/hr to 88.5km/hr)	50 km/hr.
Median	Required	Median separated
Multilane highway type	Rural/suburban multilane highway	Suburban multilane highway

In this study, the selected road is taken as two road sections i.e., section 1, from Haile Garment to Tuludimtu and section two from Tuludimtu to Goro. This is due to the influence of the Addis-Adama expressway which is located in between the starting and ending of the road. This significantly affects the characteristics of the traffic flow in which to get the maximum effect of heavy traffic, the primary data were collected in the direction of traffic flow from Tuludimtu to Hailegarment and Tuludimtu to Goro.

3.2. Determining consistency of PCE in HCM 2010

In order to determine the consistency of PCE values in HCM 2010 in representing the actual condition of multilane highways of Ethiopia, the following parameters were used:

A. assumptions and methodology mentioned on HCM 2010 which are used to determine PCE values
B. similar studies: determining the say of different similar studies in the consistency of PCE values to their local condition
C. use local data and determine PCE values using similar methodology as HCM 2010

3.3. Population and Sampling Technique

The populations of the study are road users of the selected road section, from Haile Garment to Tuludimtu to Goro. According to Ethiopian Roads Administration (ERA), there are around 20,000 vehicles which use both the old Addis Adama road and the Expressway per day. And the Expressway has the capacity of giving service for 15,000 vehicles per day. As the selected road sections are designed to connect to Addis Adama roads, the population of the study will be around 20,000 vehicles and additional vehicles from nearby residents.

The sampling technique used is random sampling in which vehicles which occur in the selected data collection time are analyzed. In addition, specific locations of the road with different grades were selected to consider the variation of PCEs relative to percent grade of the road.

However, to ensure that the sampled vehicles represent the total population and to produce a 95% confidence of achieving maximum tolerable error, the minimum sample size is determined by the following equation (HCM, 2010):

$$n = (1.96*S)^2/(E_T)^2 \text{……………………….} \textit{Equation 11}$$

Where: n = Sample size

S= standard deviation

E_T = Maximum tolerable error

In this study, a maximum tolerable error of $\pm$1km/hr with a minimum confidence level, which is 95% and a standard deviation of 8.05km/hr is considered (Addisu. T., 2021; Roger et al., 2011, Robertson, H.D.,1994; Box, P.C., and Oppenlander J.C., 1976; and Oppenlander, J.C., 1963). Hence, the minimum sample size was determined as:

$n = (1.96*8.05)^2/1^2 = 248.9$……………………….*Equation 12*

The actual number of vehicles sampled was above the minimum value. Every vehicle which passes the trap length is analyzed and data is extracted from the recorded video.

3.4. Data Collection and Extraction

3.4.1 Data Collection

In this study, before collecting the main data which will be used for determining PCEs, the peak hour of the selected road was identified by conducting a 12hr traffic volume count. For two days, on Tuesday and Thursday, video camera recordings were made to collect a traffic volume count. The cameras were set some distance away from the data collection point from 6:00am to 18:00 pm. The traffic volume count was made for every 15 minute interval and by adding consecutive 15 minute traffic volume counts for an hour, then the peak hour volume and the peak hour was determined. Accordingly, the peak hour volume was determined to be 1639veh/hr and the respective peak hour is from 6:15am to 7:15am.

Table 3.2 Peak hour determination

Time period		Number of vehicles	Cumulative number of vehicles per hour
From	To		
6:00	6:15	361	
6:15	6:30	389	
6:30	6:45	403	
6:45	7:00	469	1622
7:00	7:15	378	**1639**
7:15	7:30	363	1613
7:30	7:45	352	1562
7:45	8:00	384	1477
8:00	8:15	370	1469
8:15	8:30	371	1477
8:30	8:45	357	1482
8:45	9:00	271	1369
9:00	9:15	294	1293
9:15	9:30	303	1225
9:30	9:45	277	1145
9:45	10:00	201	1075

10:00	10:15	321	1102
10:15	10:30	441	1240
10:30	10:45	472	1435
10:45	11:00	279	1513
11:00	11:15	272	1464
11:15	11:30	316	1339
11:30	11:45	219	1086
11:45	12:00	271	1078
12:00	12:15	269	1075
12:15	12:30	268	1027
12:30	12:45	270	1078
12:45	13:00	257	1064
13:00	13:15	260	1055
13:15	13:30	290	1077
13:30	13:45	252	1059
13:45	14:00	270	1072
14:00	14:15	260	1072
14:15	14:30	252	1034
14:30	14:45	306	1088
14:45	15:00	285	1103
15:00	15:15	216	1059
15:15	15:30	268	1075
15:30	15:45	274	1043
15:45	16:00	277	1035
16:00	16:15	274	1093
16:15	16:30	275	1100
16:30	16:45	321	1147
16:45	17:00	294	1164
17:00	17:15	303	1193
17:15	17:30	325	1243
17:30	17:45	346	1268
17:45	18:00	197	1171

After determining the time of data collection, eight (8) different locations which satisfy the required percent of grade and length of grade were selected. The data were collected by means of photographic method using a portable video camera. The portable video cameras were adjusted some distance away from the selected location in order to capture vehicles within the specified trap length, and set to record for an average of one to one and half hours during peak hour. The numbers of data collection sites were fixed to get the desired %grade of the road and length of the grade. The calculation of the grade length entails considering the linear segment of the grade itself along with 25% of the length of the vertical curve at both ends. In the case of two consecutive upgrades, it is necessary to account for 50% of the length of the vertical curve that connects them within the length calculation for each individual grade (HCM, 2010).

Percent grade and length of grade of the selected road segment was extracted from the geometric design data of the road which was collected from Ethiopian Roads Administration head office and characteristics of the road was determined from an annual report prepared by Addis Ababa City Roads Authority head office (Road resource inventory report, 2020). The data which is collected using portable digital cameras comprise; vehicle types, travel time, percent composition of different vehicle categories, and average/mean speed of vehicles.

Table 3.3 Description of data collection points

For Upgrades							
It. No.	% Grade	Length(m)	Chainage	Coordinate	Video	Grade%	Length of Grade
1	≤2	0-0.4	19+500	8.8920812,388133682	20221212_071905	1.46	327.484
		0.4-0.8	7+160	8.882448, 38.757316	20221208_062059	1.847	740.977
2	>3-4	0-0.4	15+600	8.8605788,38.8192513	20221216_072959	3.97	296.882
		0.4-0.8	23+000	8.9232495,38.8191910	20230125_073048	3.2	617.348
3	>4-5	0-0.4	27+360	8.9572124,38.835425	20221230_073006	4.005	184.676
		0.4-0.8	25+200	8.94214895,38.823648	20221216_063001	4.4	479.7
4	>6	0.4-0.8	2+500	8.8932909, 38.7516603	20221207_061623	7.5	559.3995
For Downgrades							
It. No.	% Grade	Length(m)	Chainage	Coordinate	Video	Grade%	Length of Grade
1	<4	0.8-1.2	21+900	8.9131274,38.8181520	20221220_070042	-0.8	856.451

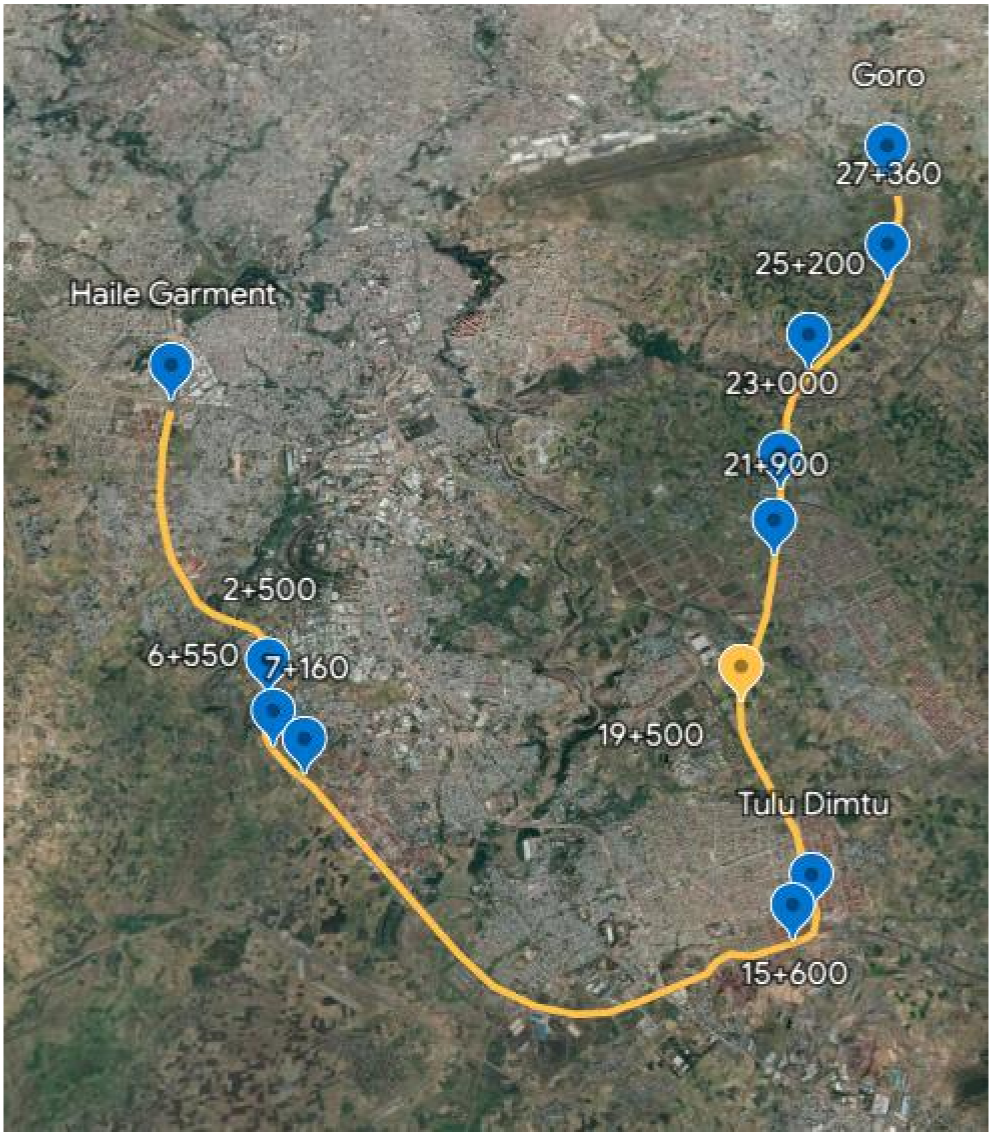


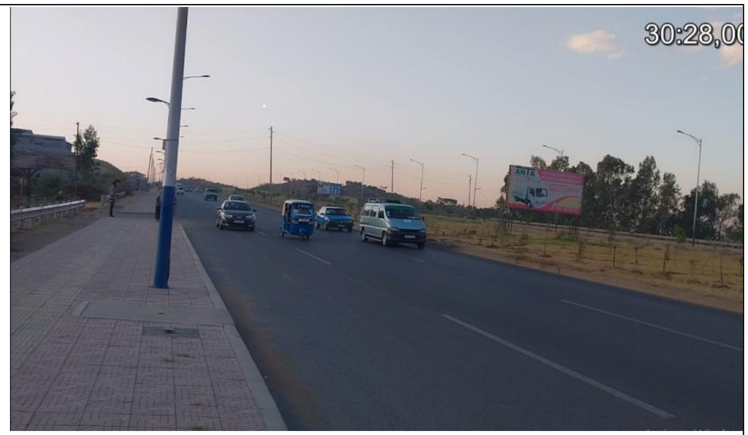
Figure 3.2 Data collection points (Source: Google Earth)

Description of the data collection locations along with photo is tabulated in the following table.

Table 3.4 Description of data collection Locations

For Upgrades			
It. No.	**Chainage**	**Coordinate**	**Photo**
1	19+500	8.8920812,388133682	
	7+160	8.882448, 38.757316	
2	15+600	8.8605788,38.8192513	

	23+000	8.9232495,38.8191910	
3	27+360	8.9572124,38.835425	
	25+200	8.94214895,38.8236488	

4	2+500	8.8932909, 38.7516603	
For Downgrades			
It. No.	**Chainage**	**Coordinate**	**Photo**
1	21+900	8.9131274,38.8181520	

The vertical alignment data of the selected road is tabulated in Appendix A.

3.4.2 Data Extraction

The type of vehicle and the time of entry and exit from a 25-meter trap were recorded in the video. Using the trap length and the duration of travel, the speed of each vehicle was calculated and prepared for further analysis.

Furthermore, percent composition of heavy vehicles was extracted from the recorded video to get 2,4,5,6,8,10,15,20,25 percent heavy vehicles for upgrades and 5,10,15,20 percent heavy vehicles for downgrades. The video was recorded for one to one and half hour, however, the peak 15 minute record was used for data extraction. For percent of heavy vehicles which cannot be extracted from a 15 minute record, one to five minute flow data were used (Roess 2004).

3.4.3 Methods of Data Analysis

The objective of this study is to determine the reliability of passenger car equivalents (PCEs) on multilane highways with local conditions, using the same investigation method as the HCM 2010. Therefore, the **Flow Rate and Density Method** was adopted for this research since this method was also used in HCM 2010.

$$PCE = \frac{1}{P_T}\left(\frac{q_B}{q_M} - 1\right) + 1 \text{………………………} \textit{Equation 13}$$

Where: q_B = equivalent passenger car only flow rate for a given v/c ratio,

q_M= mixed flow rate, and

P_T= truck proportion in the mixed traffic flow

Since speed is the critical parameter in multilane highways, it will significantly affect the value of PCE. Accordingly, the **Speed Area** method was also used to evaluate the impact of different investigation methods on PCE values, .

$$PCE_i = \frac{V_c / V_i}{A_c / A_i} \text{………………………} \textit{Equation 14}$$

Where, PCE_i = PCE value for vehicle type i

Vc = speed of standard vehicle

Vi = speed of i^{th} type of vehicle

Ac = physical rectangular area of standard car

Ai = physical rectangular area of i^{th} type of vehicles

Table 3.5 Average dimension of vehicles and their category

Vehicle category	Vehicles included	Average dimension(m)		
		Length (m)	Width (m)	Area (m2)
Two-wheeler(2W)	Motorcycle	2.11	0.81	1.72
Three-	Bajaj	2.75	1.32	3.63

wheeler(3W)				
Car/passenger car	passenger cars, taxis, ditz, Pick-up, Land Rovers, Land Cruisers, minibus taxi, Vans	4.34	1.736	7.535
Bus	> 27 seats, Bus, City Bus, Long Bus	11.43	2.47	28.18
Light Truck	ISUZU	6.25	1.6	10
Medium Truck	3.5 – 7.5 tones, Single Unit Truck, FSR ISUZU, SINO Truck	8.77	2.45	21.48
Articulated	Articulated Truck, Trailer Truck	17.85	2.45	43.73

The other method of investigation used to obtain results for conditions that could not be obtained from field observation is the **Simulation Method with PTV VISSIM.**

3.5.3.1 Steps Followed for Simulation Method

The simulation method is a valuable approach utilized in traffic studies and analysis to determine PCEs. This method offers the advantage of analyzing conditions that may not be feasible or practical to assess in real-world site conditions or during data collection.

In this study, PTV Vissim version 9 is utilized for determining PCEs through the Simulation Method.

3.5.3.1.1 Input Parameters and Model Settings

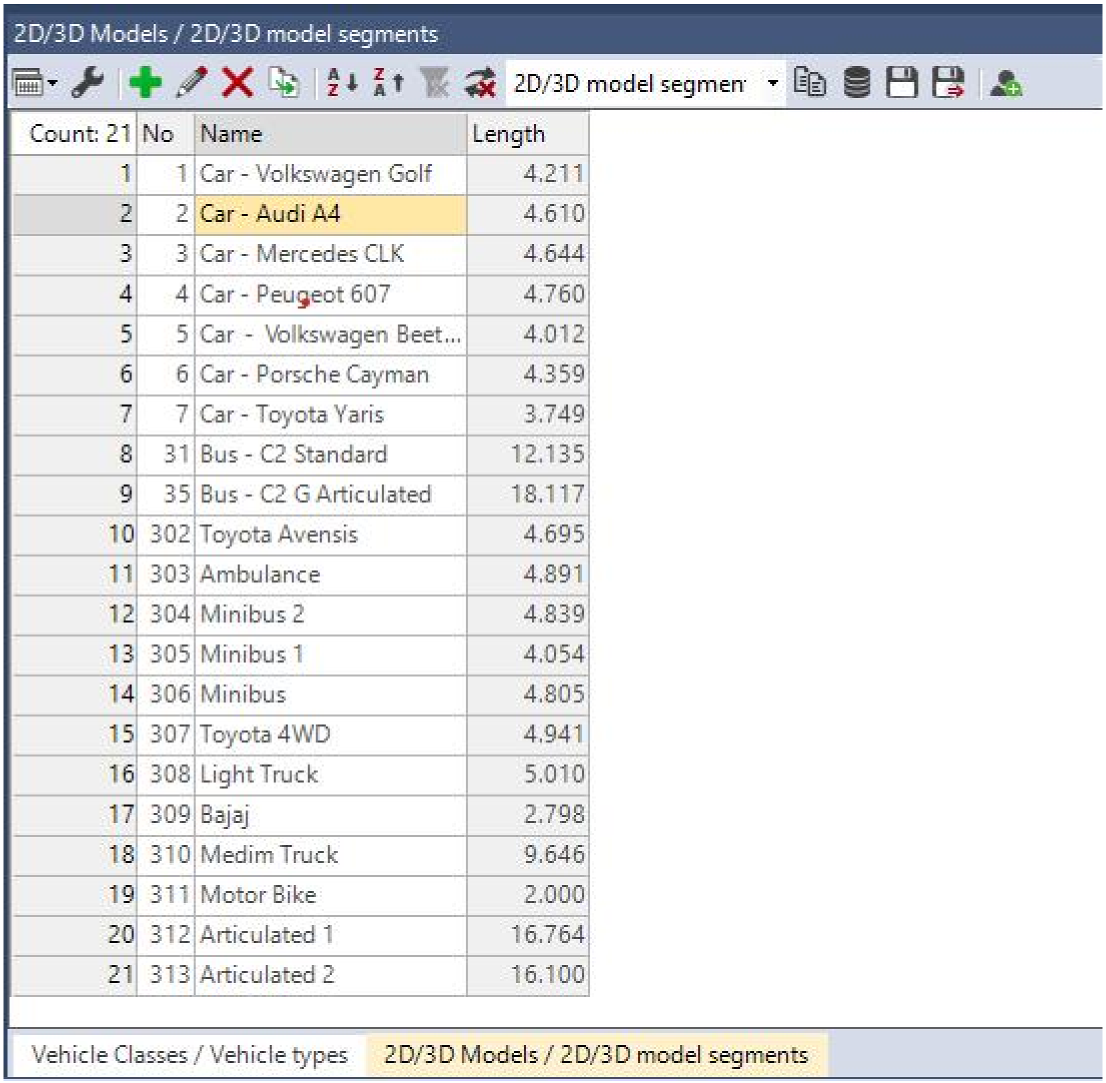
PTV VISSIM is a versatile tool for modeling and analyzing traffic flow, including the determination of Passenger Car Equivalency. It requires various inputs related to network geometry, traffic demand, vehicle data, and behavior models, and it provides outputs in the form of simulation results, and visualization tools to aid in traffic engineering and planning. Therefore, to address the objective of this study the following data inputs were considered.

A. Road model: A 3.6m*3 lane road with a total of 10.8m carriageway width, which is similar to the selected route, is modeled. Hence the selected road is located in Addis

Ababa surrounded by resident houses and different factories; the link behavior of the road was modeled as Urban Motorized.

Figure 3.3 Road model at data collection point 27+360

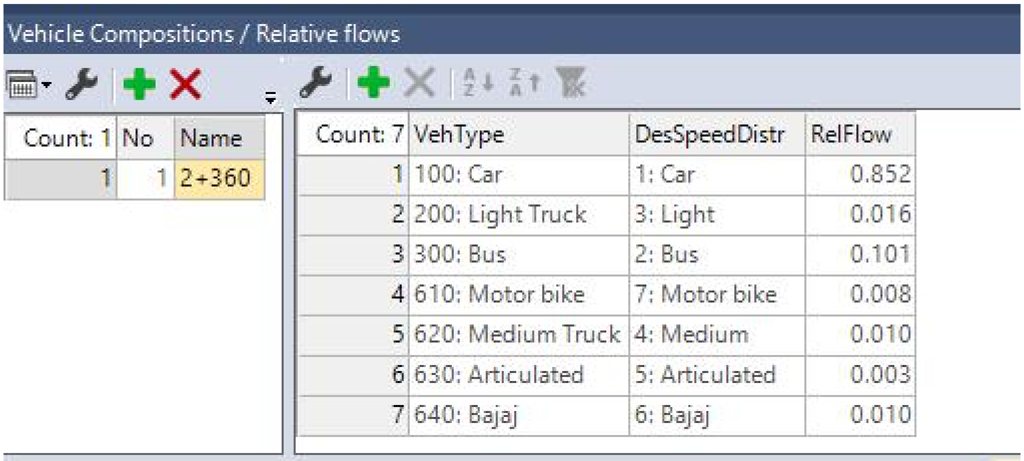
B. Vehicle Type/Model: To ensure a comparable vehicular combination to the actual collected data, vehicle types/models were chosen from the software library. Additionally, for vehicle models not available in the software's default library; other vehicle models were obtained from the official website of the PTV group, v3d.ptv american.com.


2D/3D Models / 2D/3D model segments

Count: 21	No	Name	Length
1	1	Car - Volkswagen Golf	4.211
2	2	Car - Audi A4	4.610
3	3	Car - Mercedes CLK	4.644
4	4	Car - Peugeot 607	4.760
5	5	Car - Volkswagen Beet...	4.012
6	6	Car - Porsche Cayman	4.359
7	7	Car - Toyota Yaris	3.749
8	31	Bus - C2 Standard	12.135
9	35	Bus - C2 G Articulated	18.117
10	302	Toyota Avensis	4.695
11	303	Ambulance	4.891
12	304	Minibus 2	4.839
13	305	Minibus 1	4.054
14	306	Minibus	4.805
15	307	Toyota 4WD	4.941
16	308	Light Truck	5.010
17	309	Bajaj	2.798
18	310	Medim Truck	9.646
19	311	Motor Bike	2.000
20	312	Articulated 1	16.764
21	313	Articulated 2	16.100

Figure 3.4 Vehicle models selected for the simulation

C. Vehicle Category/Class and vehicle composition: In this study, vehicles are classified into seven vehicular categories/classes. The total number of vehicles and composition of each vehicle model and vehicle class was taken as an input. The total number of vehicles and composition of vehicles is different for each data collection point and this data is inserted separately for each of them.



Count: 1	No	Name
1	1	2+360

Count: 7	VehType	DesSpeedDistr	RelFlow
1	100: Car	1: Car	0.852
2	200: Light Truck	3: Light	0.016
3	300: Bus	2: Bus	0.101
4	610: Motor bike	7: Motor bike	0.008
5	620: Medium Truck	4: Medium	0.010
6	630: Articulated	5: Articulated	0.003
7	640: Bajaj	6: Bajaj	0.010

Figure 3.5 Vehicle Type and Vehicle composition

D. Car Following Model

Traffic analysis in PTV Vissim works by considering the Car following model. There are two types of car following models, Wiedemann 99 and Wiedemann 74. The former one is used for freeways with no or less traffic control, and the latest model is for traffic conditions with a considerable traffic control. The traffic condition in multilane highways is controlled by signal intersections and/or by roundabouts; the Wiedemann 74 car following model is adopted for this study. In Wiedemann 74 car following model, there are three parameters which are used to calculate the car following safety distance:

$$ax + (bx_{add} + bx_{mult} * z) * \sqrt{\vec{v}} \quad , z \in [0,1] \quad \text{……………………….}\textit{Equation 15}$$

Where, ax= average standstill distance

bx_{add} = additive part of the safety distance

bx_{mult} = multiplicative part of safety distance

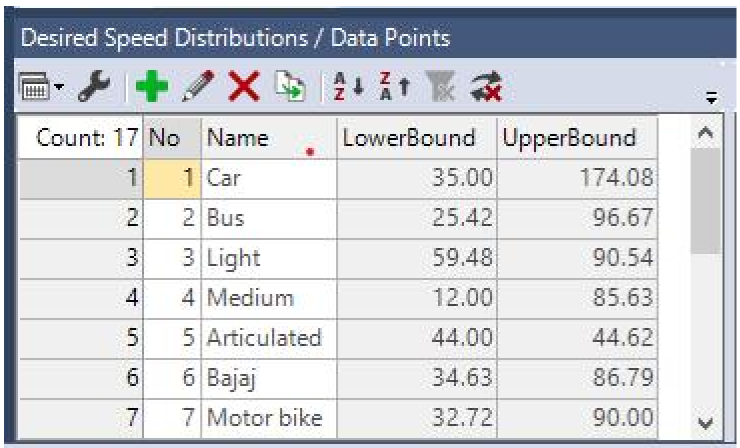
Z = constant (0, 1)

V = speed of a vehicle

The model is based on the human perception threshold aiming to avoid collision with leader vehicles while maintaining desired speed conditions prevail. In the model, speed parameter and difference in speed between the subject vehicle and the lead vehicle are used as analysis parameters. In Wiedemann 74 car following model, average standstill distance, additive part of the safety distance and multiplicative part of safety distance are used to calibrate model.

D. Desired Speed Distribution

PTV Vissim utilizes the desired speed distribution of vehicles to model the range of speed at which drivers aim to travel based on their individual preference. In this regard, the lower and upper bound of vehicle speeds were specified as input parameters.


Desired Speed Distributions / Data Points

Count: 17	No	Name	LowerBound	UpperBound
1	1	Car	35.00	174.08
2	2	Bus	25.42	96.67
3	3	Light	59.48	90.54
4	4	Medium	12.00	85.63
5	5	Articulated	44.00	44.62
6	6	Bajaj	34.63	86.79
7	7	Motor bike	32.72	90.00

Figure 3.6 Desired speed distribution at data collection point 27+360

3.5 Calibration of the Simulation Model

To ensure the fidelity of the simulation model in reflecting real-world scenarios, it is imperative to calibrate the simulation software. Therefore, in this study, the capacity of the chosen road was employed as a reference for software calibration.

Using field data, the speed-density relationship was generated and the capacity was determined using the Green shield model.

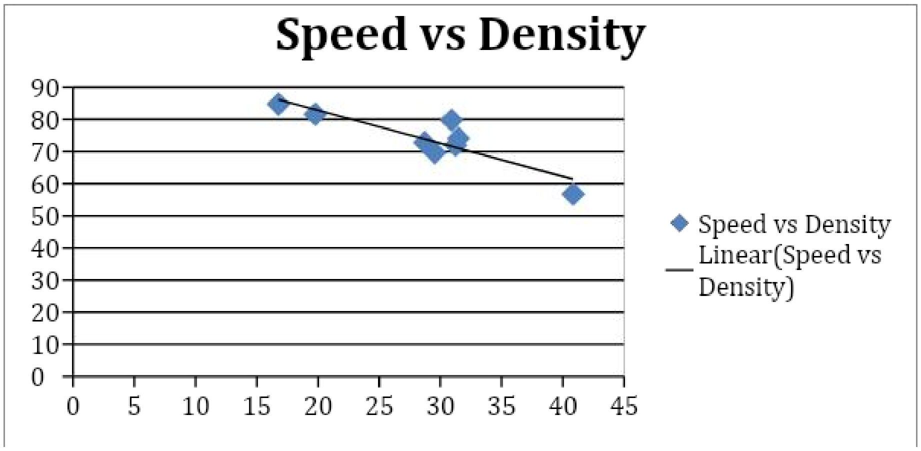


Figure 3.7 Speed density relationship using field data

After having the speed-density relationship, a Green shield model is used to determine the capacity of the chosen road:

$$Q = k_j*v-(k_j/u_f)*v^2 \text{……………………….Equation 16}$$

Where, Q = flow

k_j = Jam density

v = Speed of vehicles

u_f = mean free speed

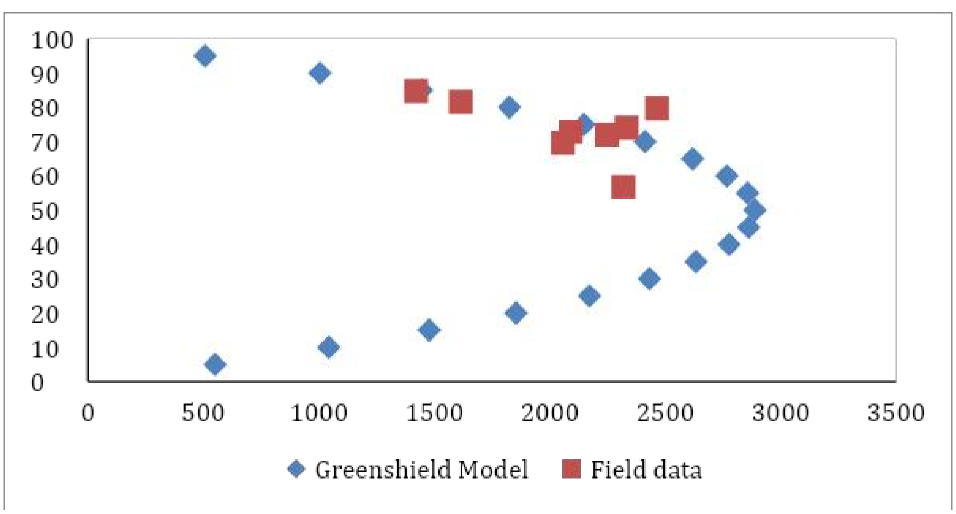


Figure 3.8 Green shield model and field data

From the Green shield model, the capacity of the selected road is determined to be 2586 pcu\hr.

Subsequent to obtaining the road capacity through field data, the model underwent calibration by adjusting its parameters to achieve a capacity value that closely approximates the field data-determined capacity. A permissible deviation of up to 10% between the field data output and simulation result was considered (FDOT, 2021). Consequently, the final values of the model parameters were determined as follows: ax= 1, $Bx_{add} = 1$ and $Bx_{mult} = 4.5$.

Speed-density relationship from the output of simulation runs is generated as.

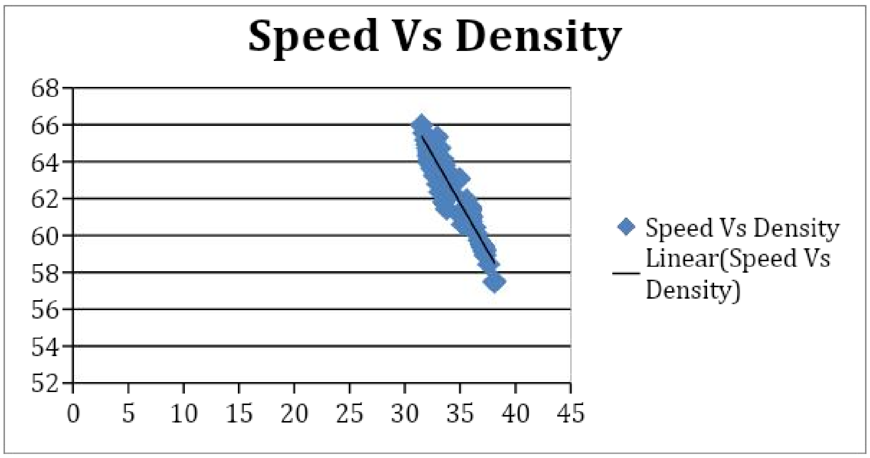


Figure 3.9 Speed density relationship using simulation output

Upon obtaining the speed-density relationship, a similar approach was employed to ascertain the maximum flow utilizing the Green Shield model, yielding a value of 2336pc/hr. The percentage difference between the maximum flow derived from field data and the simulation output amounted to 9.69%, falling within the acceptable range. Consequently, the calibrated model was deemed valid in representing the real-world conditions with an acceptable margin of error.

3.6 Validation of the Simulation Model

After calibrating the simulation model, its validity was further investigated through the use of t-distribution to ensure that the simulation outputs accurately reflect real-world field conditions. T-distribution is selected because, the standard deviation of the population is unknown and the sample size is small. To this end, the speed of all vehicle categories was compared between the field data and the simulation output, which was specifically reserved for this validation analysis.

$t_o = (Dmean-\mu) / (Sd/ n^{0.5})$ ……………………….Equation 17

$Sd^2 = \frac{E(D-Dmean)^2}{n-1}$ ……………………………….Equation 18

Where, to= t- statistics

μ= the null hypothesis

Sd= sample standard deviation

n= number of sample

The null hypothesis for paired wise difference between the two test is equal to Ho: μ=0

Table 3.6 Computation of to

Vehicle category	Speed from field data	Speed from simulation	Difference (D)	D-Dmean	$(D\text{-}Dmean)^2$
Car	50.43	72.23	21.80	12.83	164.72
Bajaj	41.13	60.21	19.08	10.11	102.30
Bus	45.37	48.45	3.08	-5.89	34.64
Light Truck	45.77	67.19	21.42	12.45	155.11
Medium Truck	39.09	39.95	0.86	-8.11	65.70
Articulated	41.48	43.76	2.28	-6.69	44.70
Motor	52.60	46.84	-5.76	-14.73	216.85
			Dmean	8.97	

$Sd^2 = 784.02/6 = 130.67$

Sd= 11.43

$t_o = 8.97/(11.43/7^{0.5}) = 2.07$

Considering a 95% confidence and 6(7-1) degree of freedom, the critical value of t is determined from t-distribution table as 2.447. Accordingly, since the value of t-statistics is less than the value of t-critical, the simulation model deemed valid in representing the real site condition.

3.7 Research Flow Chart

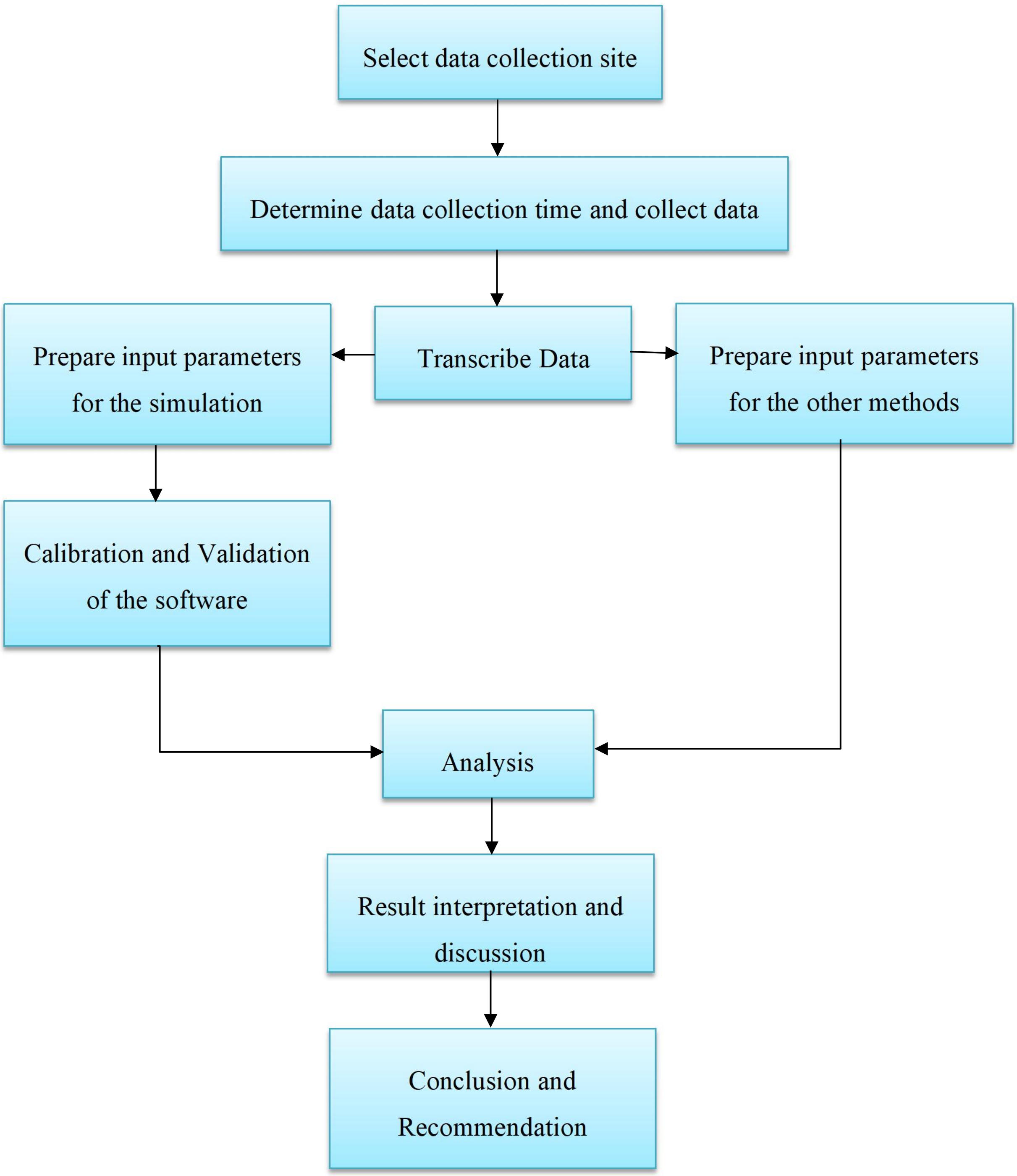


Figure 3.10 Research flowchart

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Consistency of PCE values in HCM 2010 to local condition

TRB (Transportation Research Board) dedicates significant resources to develop a standardized manual for analyzing road capacity and determining performance. This manual is widely recognized and referenced by transportation researchers and institutions globally. It is derived from various research conducted in the United States of America. Consequently, this section presents the findings on the suitability of utilizing PCE values from the HCM 2010 in local conditions.

A. Assumptions and Methodology Used in HCM 2010 to Determine PCE Values

Assumptions made in HCM 2010	Condition on the selected Road
it doesn't take in to account Presence of on street parking	There is no on street parking
it doesn't take in to account presence of bus stop that have significant use	There exist 13 bus stop stations that exhibit significant usage
it doesn't take in to account significant pedestrian activity	There exist significant pedestrian activity particularly around condominium houses located along the route
It is generally applied for rural and suburban multilane highways with uninterrupted flow	Is Suburban multilane highway

Accordingly, the second and third assumptions made by HCM 2010 do not match with the selected road condition.

B. Similar studies: Determining the say of different similar studies in the consistency of PCE values to their local condition

Girum (2016), Ararsa (2020), and Addisu (2021), in there study have determined local PCE values for various road classifications. In their research, they compared their findings with the PCE values stated in HCM 2010 and found a significant difference between the two.

C. Use local data and determine PCE values using similar methodology as HCM 2010

The last, but not the least, parameter used to assess the consistency of HCM PCE values was to utilize local data and determine PCE values using a similar methodology as employed by HCM 2010. Therefore, the following sections provide a detailed description and discussion of this method.

4.2 Variation of PCE values

4.2.1 Variation of PCE values by percent of heavy vehicles

In this subsection, variation of PCE values with percent composition of heavy vehicles is discussed for different percent grade of a road. The method used to compute PCE values is flow rate and density method.

In order to facilitate the comparison of proposed PCE values with those obtained from HCM 2010, the same percentage composition of heavy vehicles in the traffic stream was utilized. As a result, the following percentages of heavy vehicles were considered for upgrades: 4%, 5%, 6%, 8%, 10%, 15%, 20%, and 25%. However, the composition of 2% heavy vehicles, along with their respective PCE values, are not presented due to the challenges encountered in obtaining data for these specific compositions during the data collection process. And for downgrades, 5%, 10%, 15%, and 20% of heavy vehicles were considered.

Figure 4.1 depicts the correlation between PCE and the percentage composition of heavy vehicles for a grade length ranging from 0 to 0.4km and an upgrade of less than 2%. The figure demonstrates that as the percentage composition of heavy vehicles increases, the PCE value decreases. This can be attributed to the diminishing cumulative impact of heavy vehicles as their quantity rises. Furthermore, it is worth noting a substantial disparity between the proposed PCE and the PCE obtained from HCM 2010.The average deviation between these two values amounts to 175%.

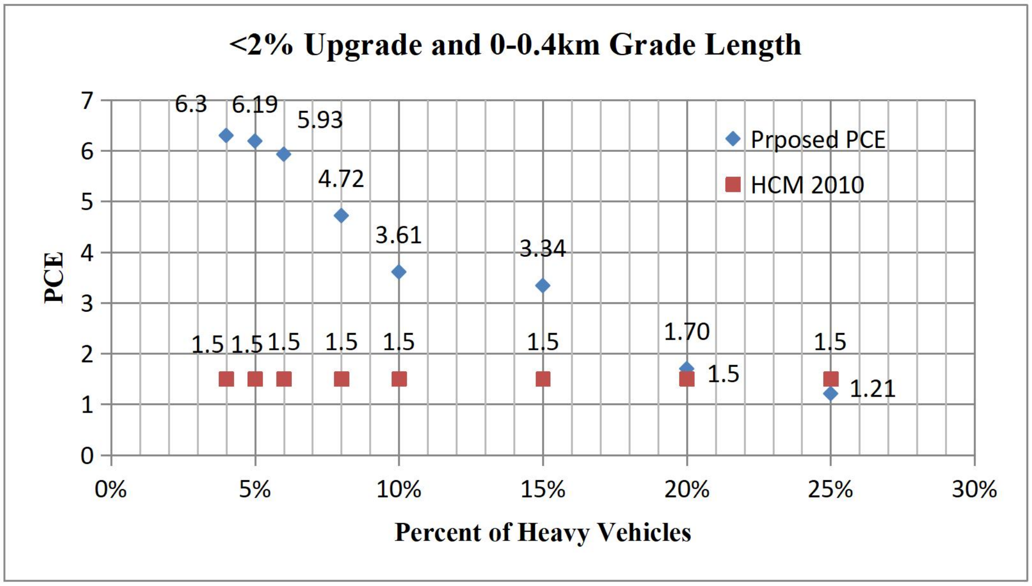


Figure 4.1 Variation of PCE with percent of heavy vehicles, for <2% upgrade and 0-0.4km grade length

Figure 4.2 presents a graphical representation of the correlation between PCE values and the percentage composition of heavy vehicles for a specific scenario involving an upgrade of less than 2% and a grade length ranging from greater than 0.4km to 0.8km. The figure demonstrates a negative relationship between the percent composition of heavy vehicles and the corresponding PCE value. This decline in PCE can be attributed to the diminishing cumulative effect of heavy vehicles as their quantity increases. Furthermore, it is worth highlighting a significant disparity between the proposed PCE values and those obtained from HCM 2010. The average disparity between these two values stands at 210%.

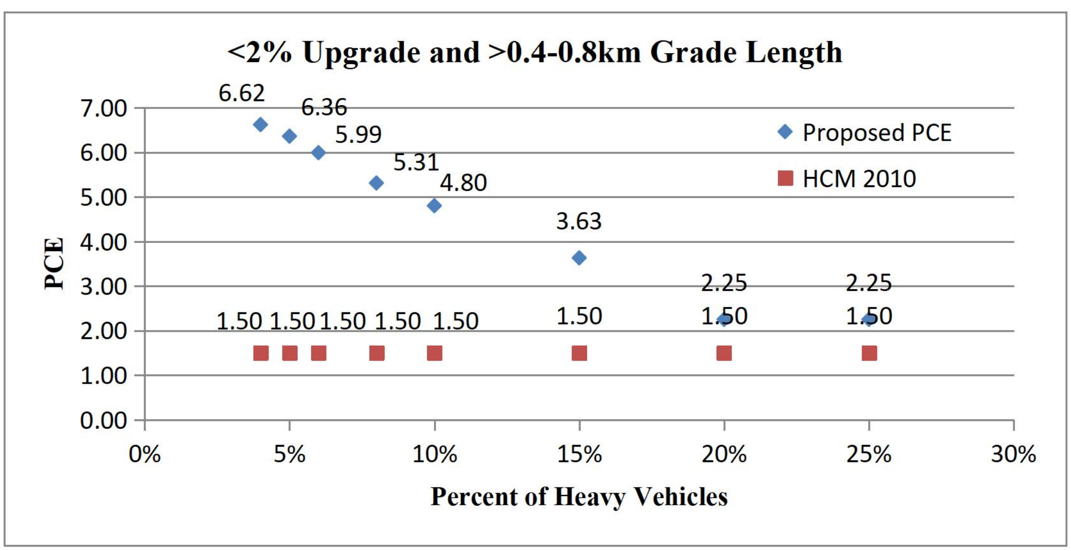


Figure 4.2 Variation of PCE with percent of heavy vehicles, for <2% upgrade and >0.4-0.8km grade length

The relationship between the PCE and the percentage composition of heavy vehicles is illustrated in Figure 4.3 for an upgrade greater than 3-4% and a length of grade greater than 0.4 to 0.8km. The figure shows a clear inverse correlation, indicating that as the percentage composition of heavy vehicles increases, the PCE value decreases. This phenomenon can be attributed to the diminishing cumulative effect of heavy vehicles as their quantity increases. Furthermore, it is worth noting a significant disparity between the proposed PCE values and those obtained from HCM 2010. The average variation between these two values is 192%.

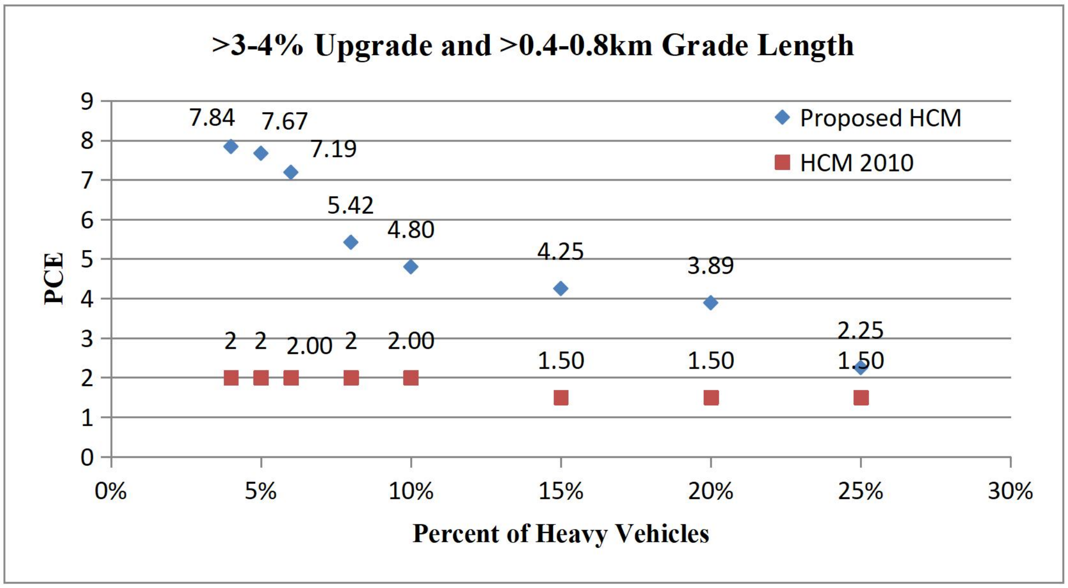


Figure 4.3 Variation of PCE with percent of heavy vehicles, for >3-4% upgrade and 0.4-0.8km grade

Figure 4.4 presents the correlation between PCE and the percentage composition of heavy vehicles for a grade length ranging from 0 to 0.4km and an upgrade greater than 4-5%. The figure effectively demonstrates that as the percentage composition of heavy vehicles increases, the PCE value decreases. This can be attributed to the diminishing cumulative impact of heavy vehicles as their quantity rises. Furthermore, it is worth noting a significant disparity between the proposed PCE and the PCE obtained from HCM 2010. The average deviation between these two values amounts to 282%.

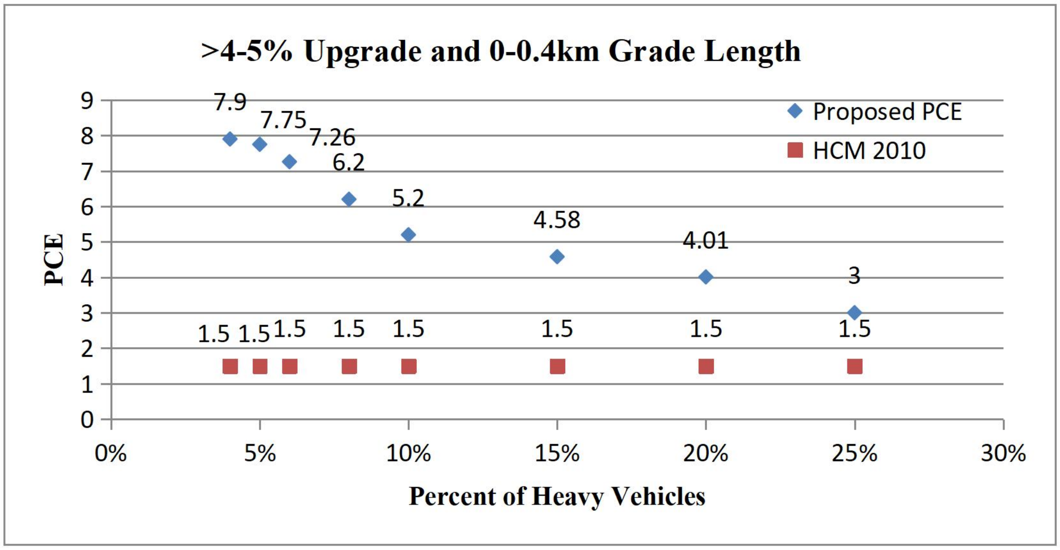


Figure 4.4 Variation of PCE with percent of heavy vehicles, for >4-5% upgrade and 0-0.4km grade length

Figure 4.5 illustrates the correlation between PCE and the percentage composition of heavy vehicles for a grade length ranging from greater than 0.4 to 0.8km and an upgrade of greater than 4-5%. A significant difference between the proposed PCE and the PCE obtained from HCM 2010 is clearly shown in the figure and the average deviation between these two values amounts 173%. In addition, the figure clearly demonstrates that as the percentage composition of heavy vehicles increases, the PCE value decreases. This can be attributed to the diminishing cumulative impact of heavy vehicles as their quantity rises.

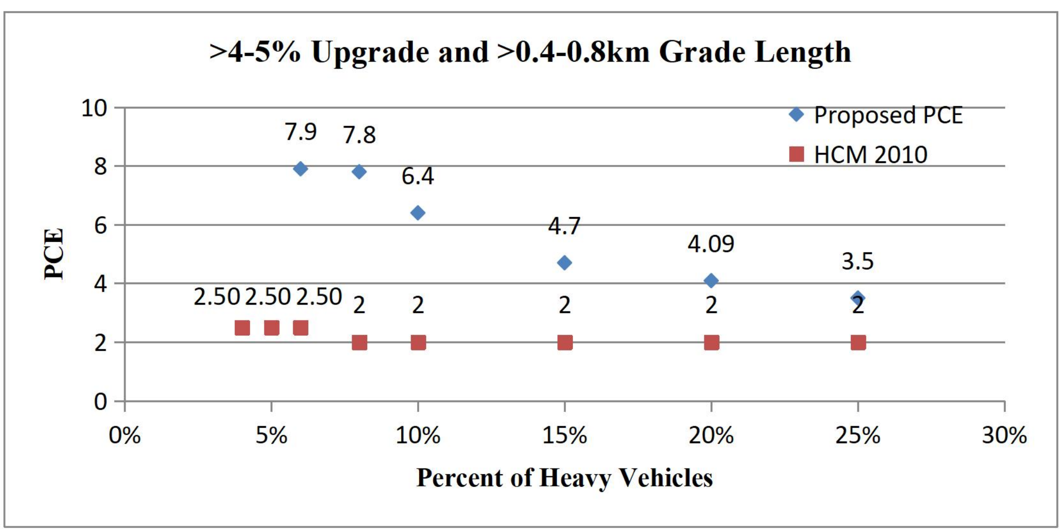


Figure 4.5 Variation of PCE with percent of heavy vehicles, for >4-5% upgrade and >0.4-0.8km grade length

The relationship between PCE and percent composition of heavy vehicles for greater than 6% upgrade and greater than 0.4 to 0.8km length of grade is shown in Figure 4.6. The figure illustrates that as percent composition of heavy vehicles increases, the PCE value decreases and this is due to the decrease in cumulative effect of heavy vehicles as their number increases. In addition, a significant difference between proposed PCE and PCE obtained from HCM 2010 is notable that the average deviation between these two values amounts 151%.

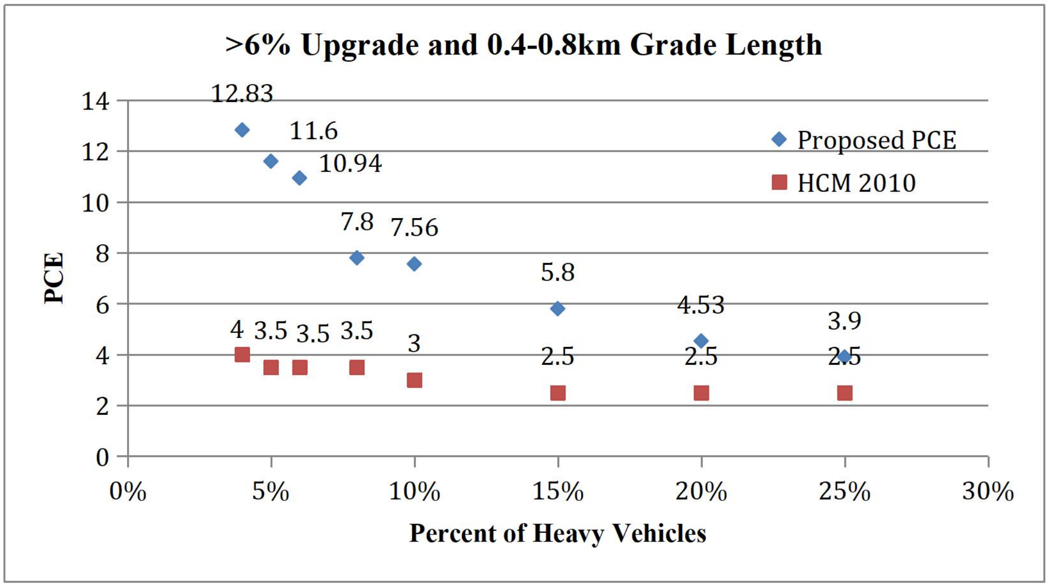


Figure 4.6 Variation of PCE with percent of heavy vehicles, for >6% upgrade and >0.4-0.8km grade length

The relationship between PCE and percent composition of heavy vehicles for less than 4% downgrade and less than 6.4km length of grade is shown in Figure 4.7. The figure illustrates that as percent composition of heavy vehicles increases, the PCE value decreases and this is due to the decrease in cumulative effect of heavy vehicles as their number increases. In addition, a significant difference between proposed PCE and PCE obtained from HCM 2010 is considered. The average disparity between these two values stands at 153%.

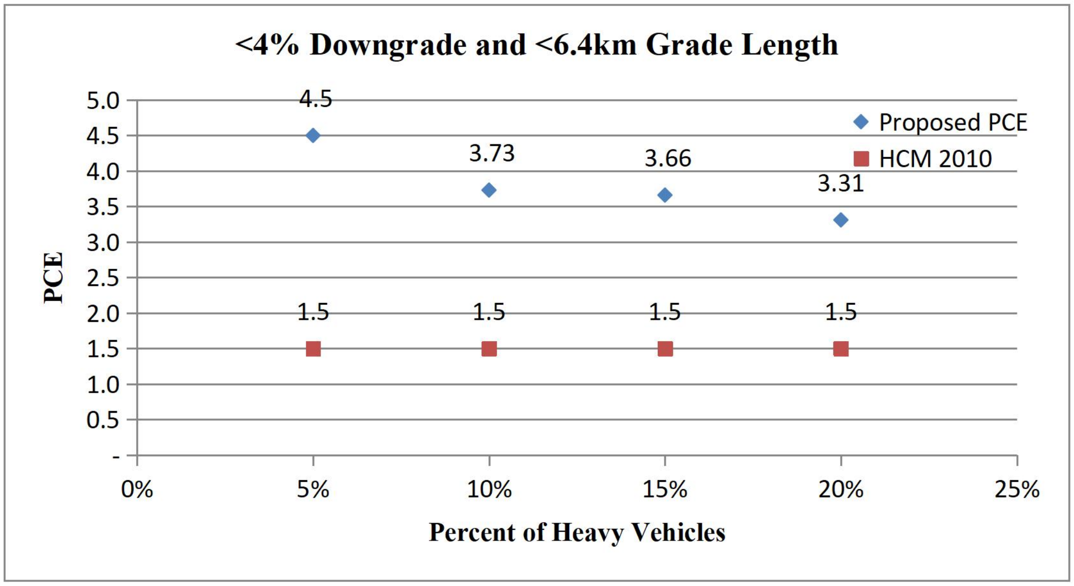


Figure 4.7 Variation of PCE with percent of heavy vehicles, for <4% downgrade and <6.4km grade length

Although there is a lack of local research on multilane highways using the same methodology, Girum (2020) conducted a study on the Addis-Adama Expressway which revealed PCE values for varying proportions of heavy vehicles. Accordingly, the finding that the PCE values decline as the number of heavy vehicles increases is consistent with both this study and the HCM 2010. In addition, the difference between local PCE values proposed by Girum (2020) and by this research with that of HCM 2010 exhibits somewhat similar variation.

4.2.2 Variation of PCE values by percent grade of the road and percent of heavy vehicle

In order to have PCE values which can be compared with HCM 2010, PCE values were determined using Flow rate and density method of investigation considering different heavy vehicle compositions which are similar with HCM 2010.

Accordingly, heavy vehicles with a composition of 4%, 5%, 6%, 8%, 10%, 15%, 20% and 25% for upgrades and 5%, 10%, 15% and 20% for downgrades were considered.

Heavy vehicles have a tendency to slow down when traveling on upgrades. This is a result of the gravitational force pulling the vehicles backward as they move against it. The impact of this phenomenon is particularly pronounced in heavy vehicles because of their substantial weight. Furthermore, as the percent upgrade of the road increases, the engine power of these vehicles becomes insufficient to maintain the same speed due to the added load and resistance. Conversely, on downgrades, the effects described above are not as significant as they are on upgrades. As a result, the PCE value, which is a factor of speed, increases as the road's incline increases, and vice versa. This relationship holds true in both HCM 2010 and other similar researches. In the following figures, this relationship is clearly shown for different percent grades of the road and percent composition of heavy vehicles.

Figure 4.8 shows variation of PCE values with respect to percent upgrade of roads, considering a traffic stream consisting of 4% heavy vehicles. The figure clearly demonstrates that both the proposed PCE values and the PCE values derived from HCM 2010 increase as the percentage grade of the road increases. Notably, the proposed PCE values significantly exceed those derived from HCM 2010, reflecting the substantial differences in local conditions. And, the average deviation between the two values is 320%.

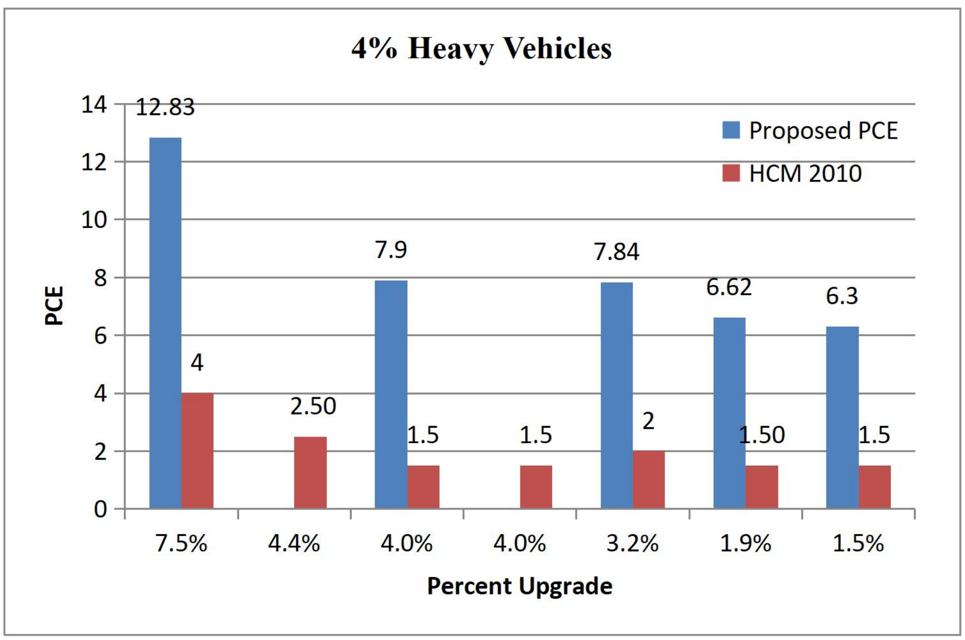


Figure 4.8 Variation of PCE values with percent grade of the road and 4% Heavy Vehicles

Figure 4.9 shows variation of PCE values with respect to percent upgrade of roads, considering a traffic stream consisting of 5% heavy vehicles. The figure clearly demonstrates that both the proposed PCE values and the PCE values derived from HCM 2010 increase as the percentage grade of the road increases. Notably, the proposed PCE values significantly exceed those derived from HCM 2010 with an average deviation of 313%, reflecting the substantial differences in local conditions.

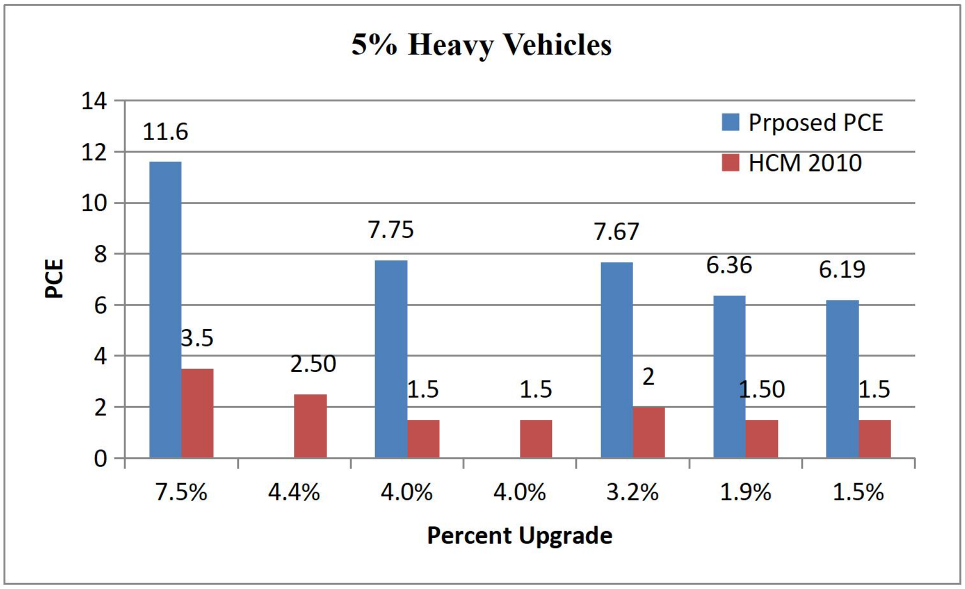


Figure 4.9 Variation of PCE values with percent grade of the road and 5% Heavy Vehicles

The relationship between PCE and the percent grade of roads, taking into account a 6% composition of heavy vehicles, is illustrated in Figure 4.10. As the percent grade of the road increases, PCE values also increase. It is evident from the figure that the proposed PCE values are higher than those obtained from HCM 2010 with an average deviation of 277%, due to significant differences in local conditions.

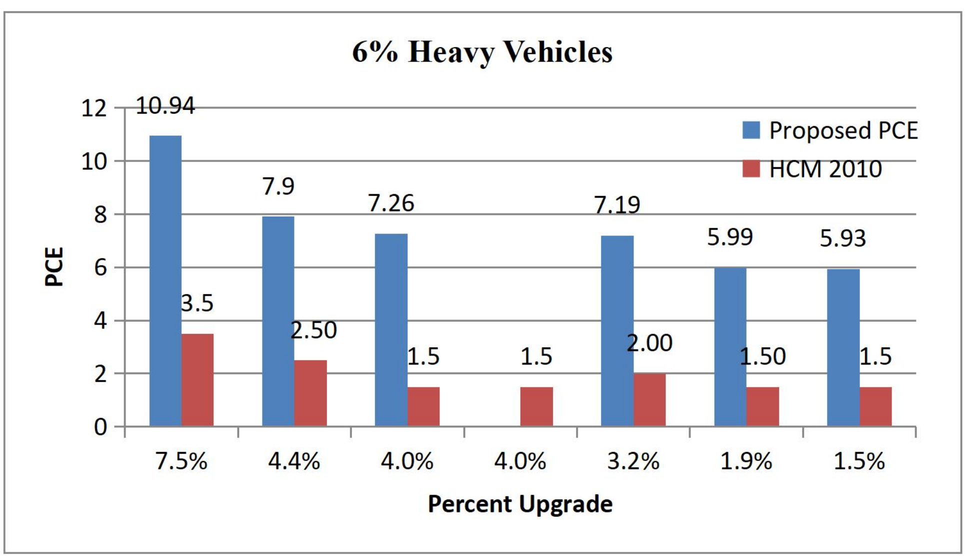


Figure 4.10 Variation of PCE values with percent grade of the road and 6% Heavy Vehicles

The relationship between PCE and the percent grade of roads, taking into account 8% composition of heavy vehicles, is illustrated in Figure 4.11. As the percent grade of the road increases, PCE values also increase. It is evident from the figure that the proposed PCE values are higher than those obtained from the HCM 2010 amounts to an average of 227% deviation, due to significant differences in local conditions.

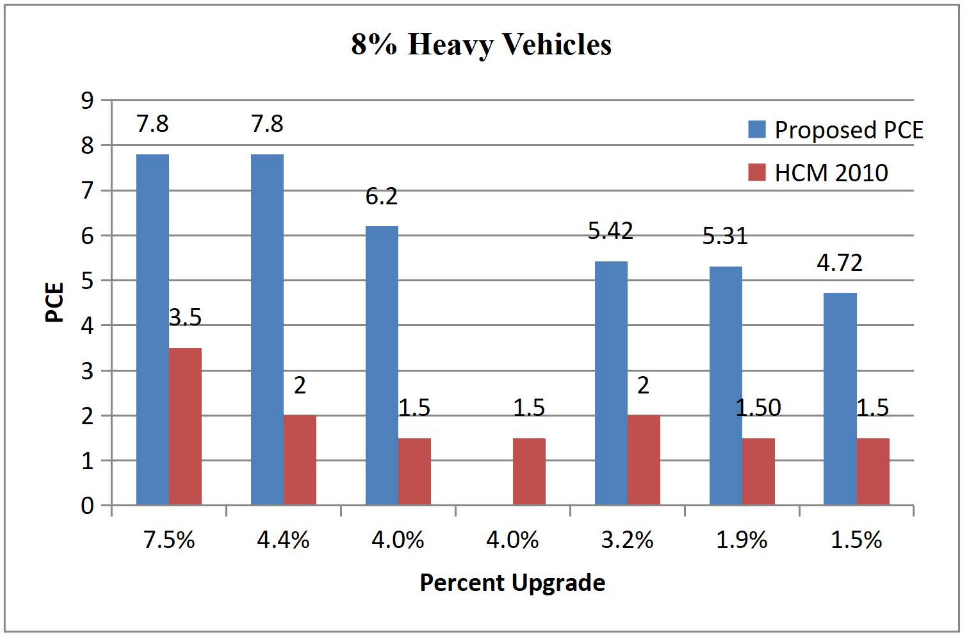


Figure 4.11 Variation of PCE values with percent grade of the road and 8% Heavy Vehicles

Figure 4.12 shows the relationship between PCE and the percent grade of roads, for a road traffic flow consisting 10% heavy vehicles. In the figure, the significance difference between proposed PCE values and PCE values obtained from HCM 2010 is clearly shown and the average difference between the two values stands at 186%.

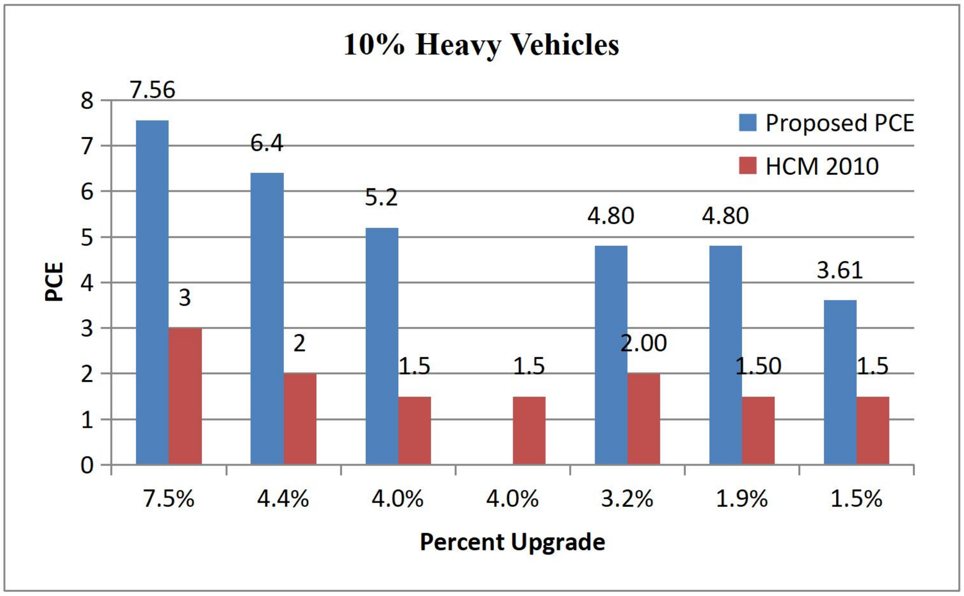


Figure 4.12 Variation of PCE values with percent grade of the road and 10% Heavy Vehicles

Figure 4.13 shows the relationship between PCE and the percent grade of roads, for a road traffic flow consisting 15% heavy vehicles. In the figure, the significant difference between proposed PCE values and PCE values obtained from HCM 2010 is clearly shown and the average deviation amounts to 153%.

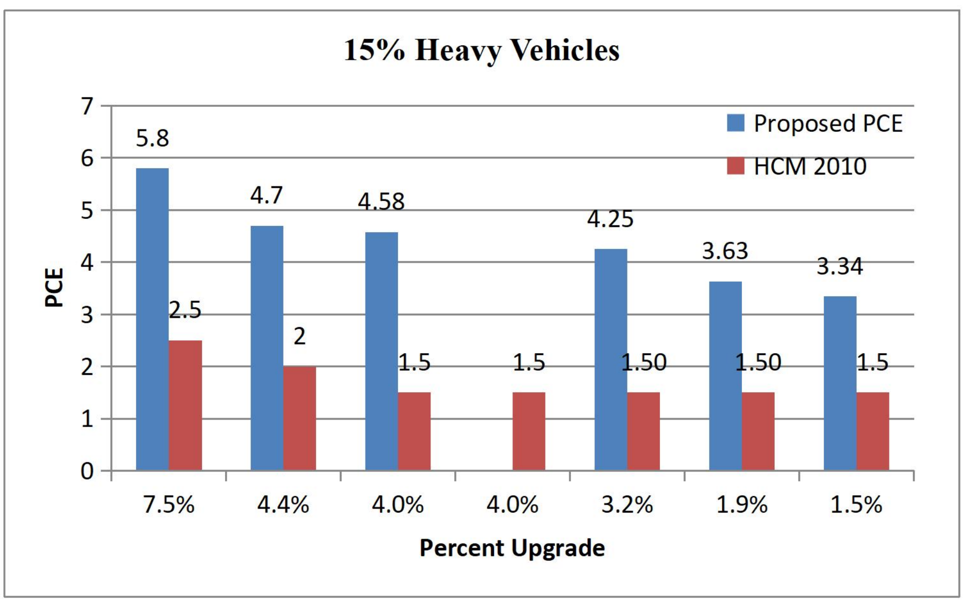


Figure 4.13 Variation of PCE values with percent grade of the road and 15% Heavy Vehicles

The relationship between PCE and the percent grade of roads is presented in figure 4.14 taking into account 20% composition of heavy vehicles. In the figure, it is shown that, the proposed PCE values are notably higher than those obtained from the HCM 2010 with an average deviation of 96%, due to significant differences in local conditions.

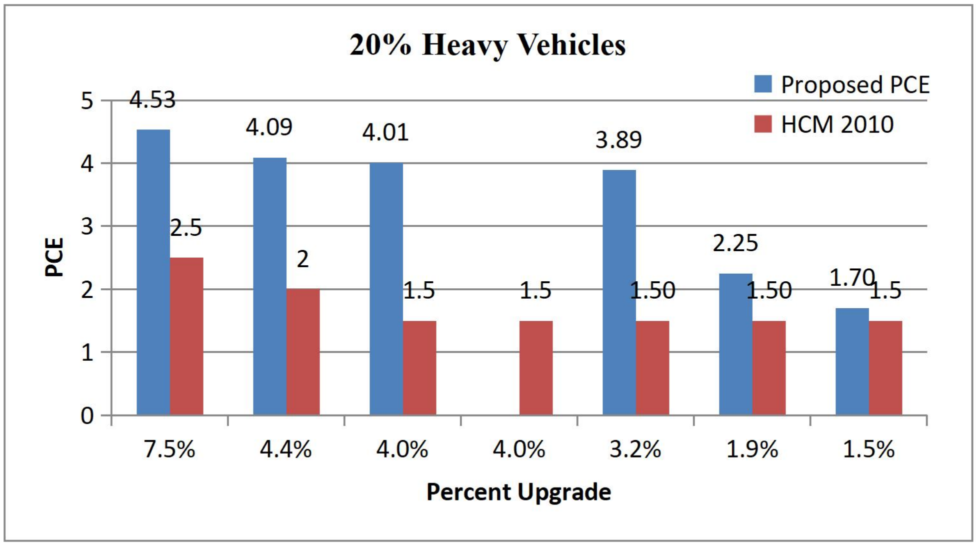


Figure 4.14 Variation of PCE values with percent grade of the road and 20% Heavy Vehicles

The relationship between PCE and the percent grade of roads is presented in figure 4.15 taking into account 25% composition of heavy vehicles. In the figure, it is shown that, the proposed PCE values are notably higher than those obtained from the HCM 2010 with an exception for 1.46% of upgrade. The average deviation between the two amounts to 52%.

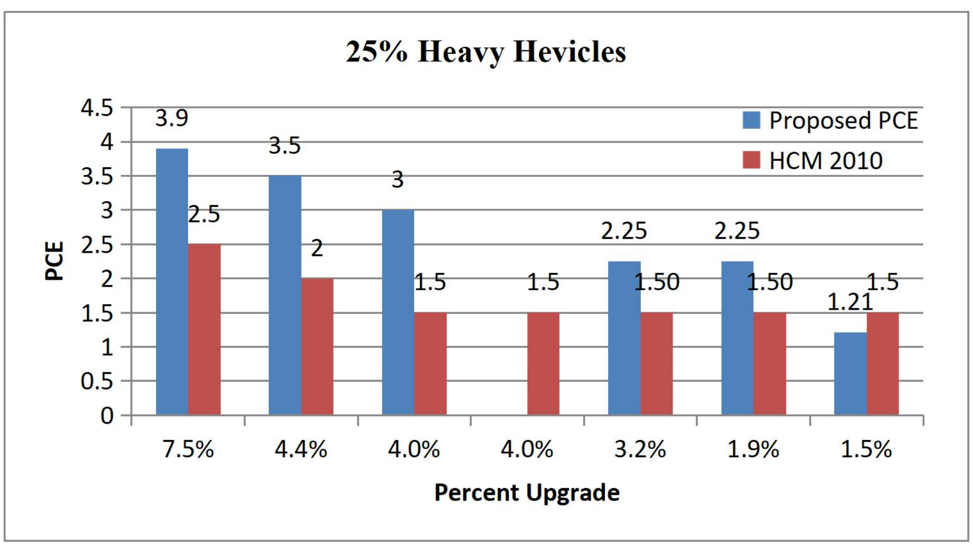


Figure 4.15 Variation of PCE values with percent grade of the road and 25% Heavy Vehicles

In the above figures, it is evident that as the percent grade of the road increases, the value of PCE also increases in a non-linear manner, and vice versa. This relationship holds true across various percentages of heavy vehicles. Furthermore, it is important to note that the PCE values obtained from field investigations or proposed PCE values exhibit significant differences when compared to those stated in HCM 2010.

4.2.3 Variation of PCE values by percent grade of the road

In HCM 2010, PCE values are presented with respect to range of percent upgrades of roads, which includes <=2, >2-3, >3-4, >4-5 and >6; and percent downgrades which includes <4, 4-5, >5-6, and >6. However, in this section, it is aimed to illustrate variation of PCE values with actual percent grade of the selected road.

Furthermore, in HCM 2010, the relationship between PCE values and the percent grade of a road is depicted as being directly proportional. Similarly, in this research, it has been observed that as the percent grade of the road increases, the PCE value also increases. This correlation is clearly demonstrated in the following section. For PCE values determined from field data, percent grade of the road with respective grade length which was collected from field investigation is presented.

Figures 4.16 and 4.17 depict the relationship between PCE values and the percentage grade of the road for a grade length ranging from 0 to 0.4km. Both figures clearly demonstrate that as the percentage grade of the road increases, the PCE values also increase. Furthermore, this relationship becomes particularly significant as the size of the vehicles increases.

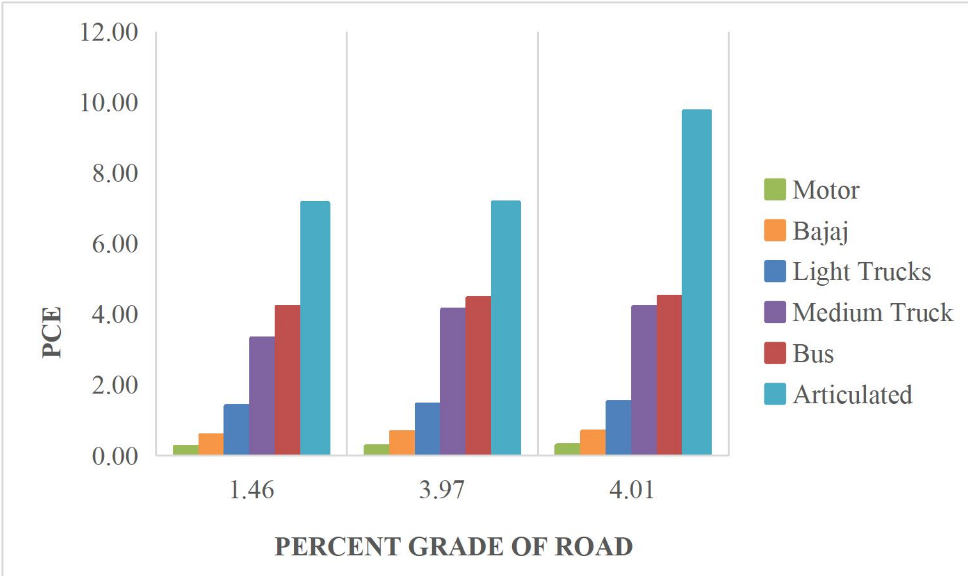


Figure 4.16 Variation of PCE values with percent of grade, 0-0.4km grade length (Using Field Data)

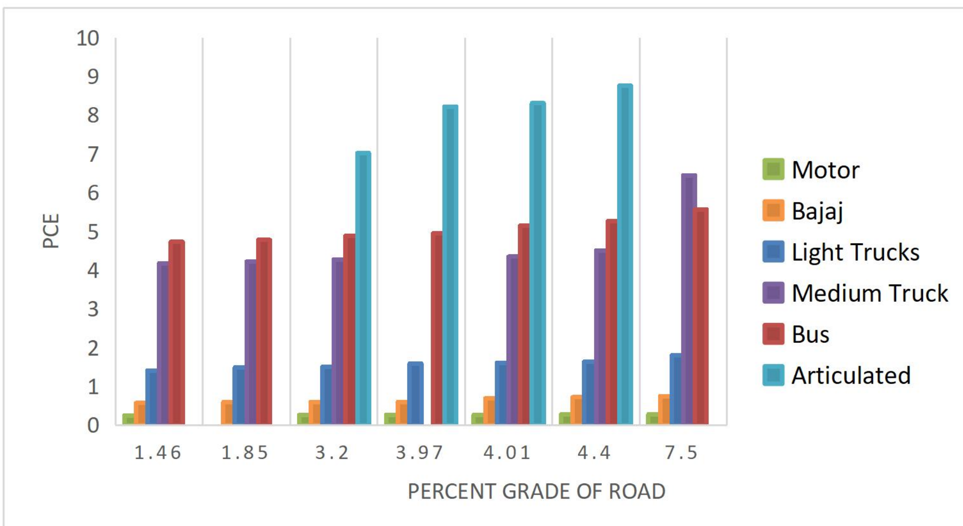


Figure 4.17 Variation of PCE values with percent of grade, 0-0.4km grade length (Using Simulation)

Figures 4.18 and 4.19 show the variation of PCE values with percent grade of the road for a grade length ranging from >0.4 to 0.8km. In both figures, it is clearly demonstrated that as the percentage grade of the road increases, the PCE values also increase. In addition, this relationship becomes significant as the size of the vehicles increases.

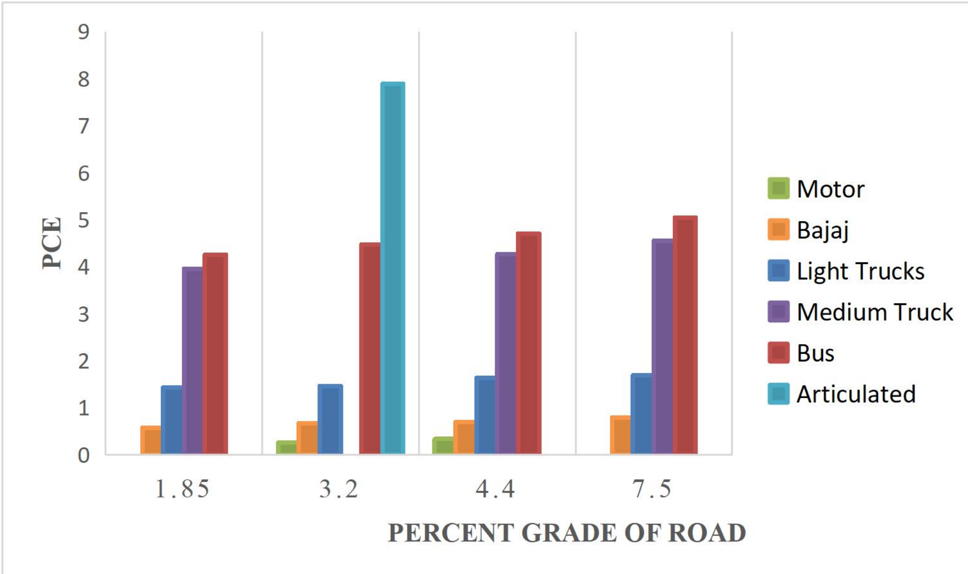


Figure 4.18 Variation of PCE values with percent of grade, >0.4-0.8km grade length (Using Field Data)

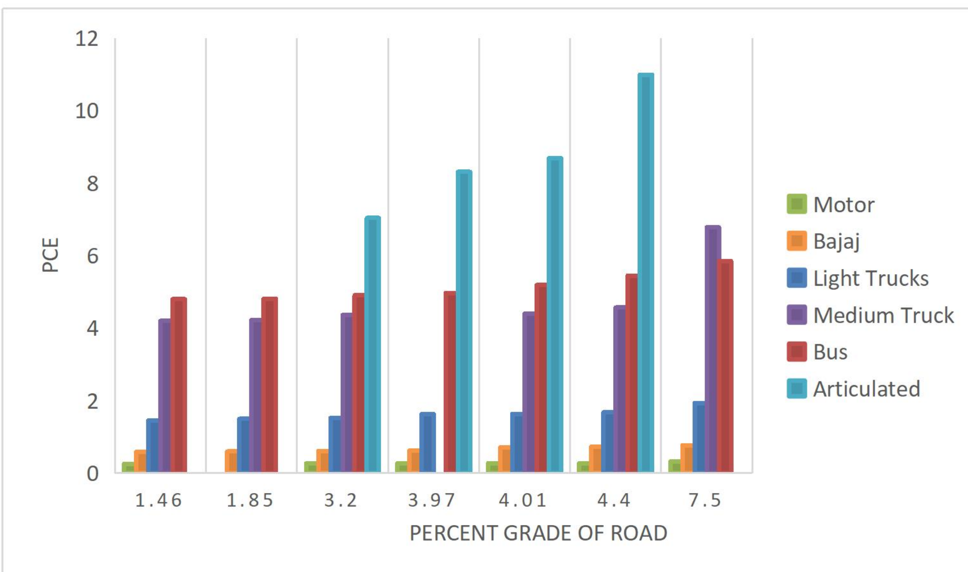


Figure 4.19 Variation of PCE values with percent of grade, >0.4-0.8km grade length (Using Simulation)

In Figure 4.20, the relationship between the percentage grade of the road and PCE for a grade length ranging from above 0.8km to 1.2km is illustrated. The figure clearly shows that the percentage grade of roads is directly proportional to PCE values. In other words, as the percentage grade of the road increases, the PCE value also increases for all vehicle categories.

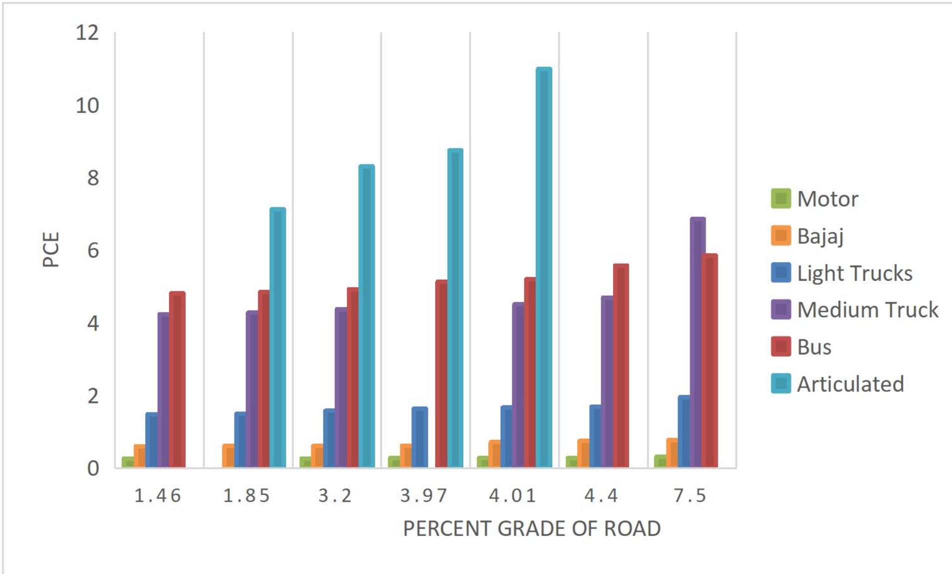


Figure 4.20 Variation of PCE values with percent of grade, >0.8-1.2km grade length (Using Simulation)

In figure 4.21, the relationship between percent grade of the road and PCE for a grade length of above 1.2km is demonstrated. From the figure, it can be seen that, percent grade of roads are directly proportional with PCE values. i.e., as the percent grade of the road increases, PCE value for all vehicle categories also increases.

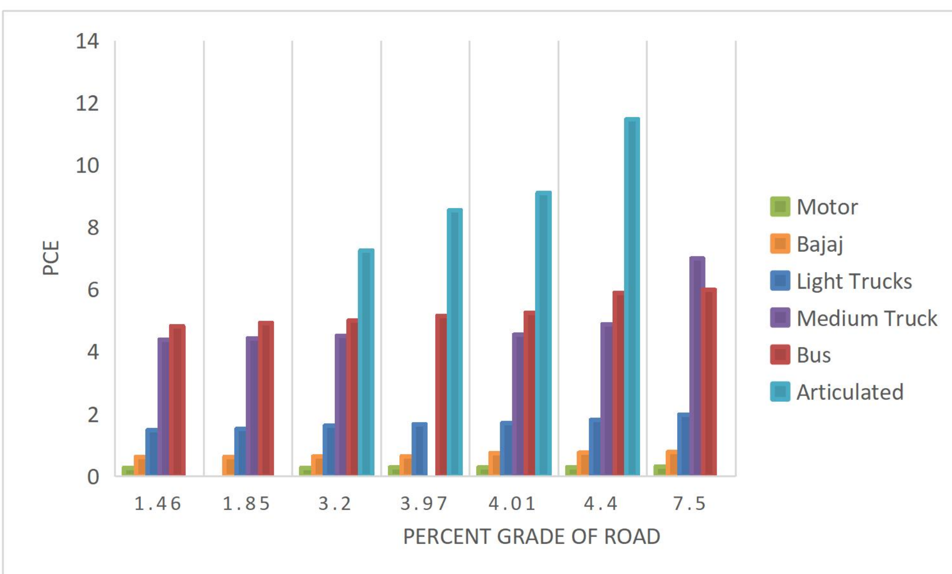


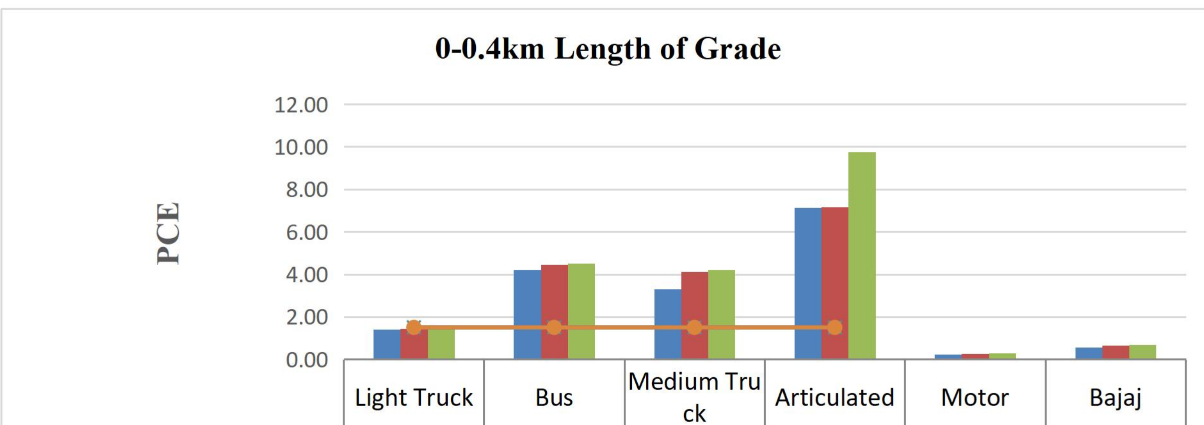
Figure 4.21 Variation of PCE values with percent of grade, >1.2km grade length (Using Simulation)

4.2.4 Variation of PCE values by vehicle Categories

The Passenger Car Equivalent (PCE) value varies among different vehicle categories under similar external conditions. This variation arises from the fact that smaller vehicles generally exhibit greater agility and maneuverability within a road segment, allowing them to operate more actively. Conversely, larger vehicles occupy more space and tend to travel at slower speeds compared to smaller vehicles. Consequently, vehicles of varying sizes and operational characteristics exert distinct effects on traffic flow dynamics. This relation between PCE and size of vehicles is explained in the same way in HCM 2010 and other related local researches (Addisu, 2021, Ararsa, 2020, Michael, 2019 etc…)

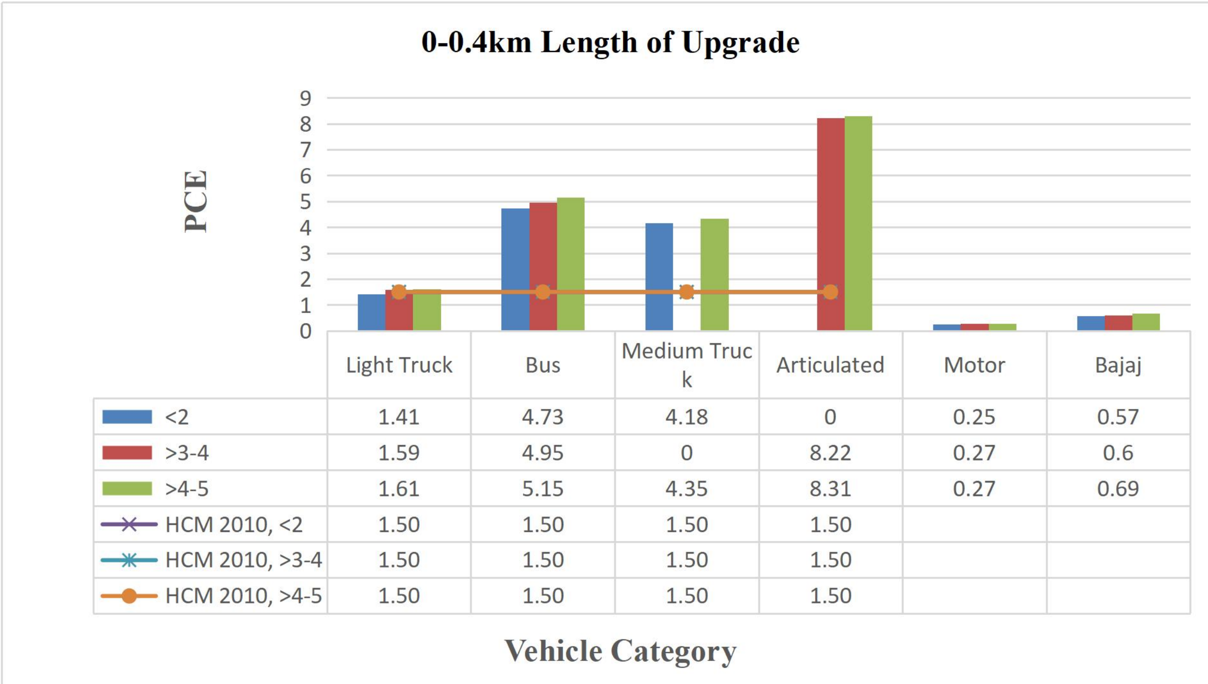
In the following figures, variation of PCE values with different vehicle categories is presented.

Figure 4.22 and Figure 4.23 demonstrates the relationship between PCE values and vehicle categories for an upgrade length of 0-0.4km. The figures highlights that there is a substantial increase in PCE value as the vehicle size increases. Additionally, the influence of the percent grade of the road is more pronounced for larger vehicles compared to smaller ones.



	Light Truck	Bus	Medium Truck	Articulated	Motor	Bajaj
<2	1.40	4.21	3.32	7.15	0.25	0.58
>3-4	1.45	4.46	4.13	7.17	0.26	0.67
>4-5	1.51	4.5	4.2	9.75	0.29	0.68
HCM 2010,<2	1.50	1.50	1.50	1.50		
HCM 2010, >3-4	1.50	1.50	1.50	1.50		
HCM 2010, >4-5	1.50	1.50	1.50	1.50		

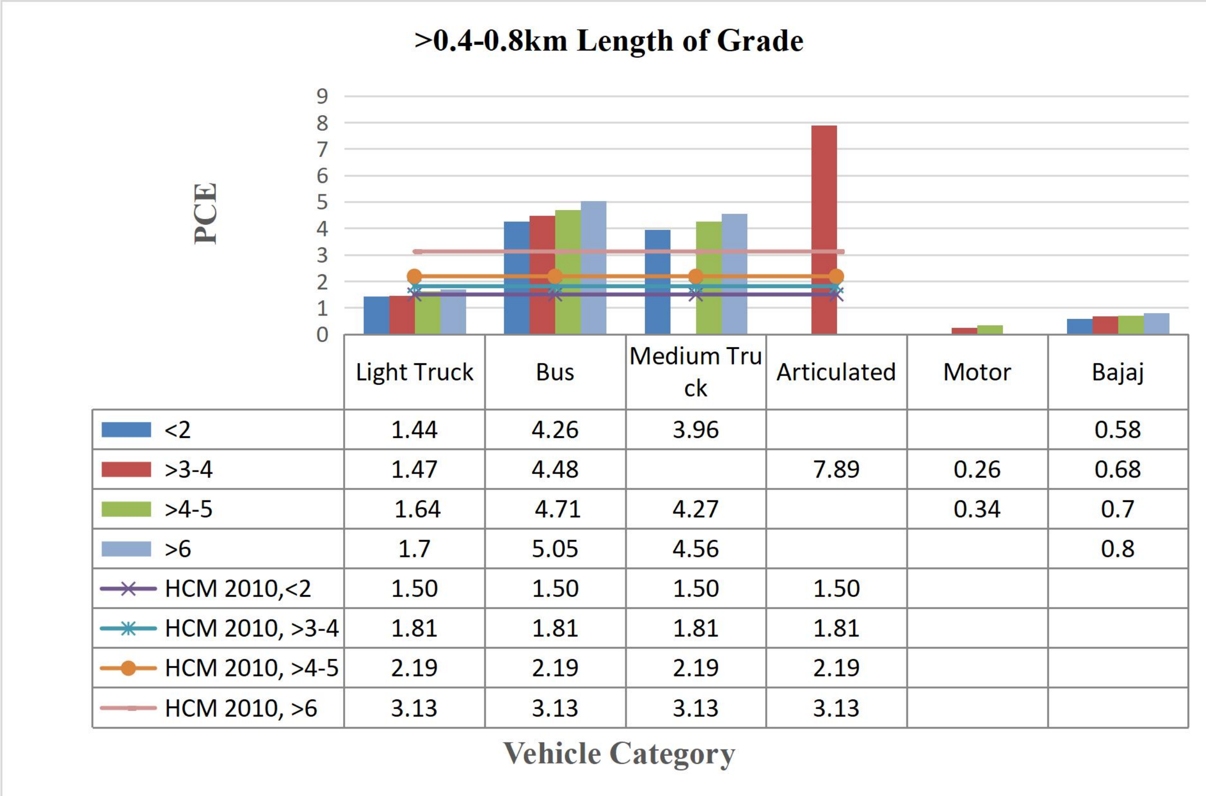
Figure 4.22 Variation of PCE values with vehicle category, for 0-0.4km length of upgrade



	Light Truck	Bus	Medium Truc k	Articulated	Motor	Bajaj
<2	1.41	4.73	4.18	0	0.25	0.57
>3-4	1.59	4.95	0	8.22	0.27	0.6
>4-5	1.61	5.15	4.35	8.31	0.27	0.69
HCM 2010, <2	1.50	1.50	1.50	1.50		
HCM 2010, >3-4	1.50	1.50	1.50	1.50		
HCM 2010, >4-5	1.50	1.50	1.50	1.50		

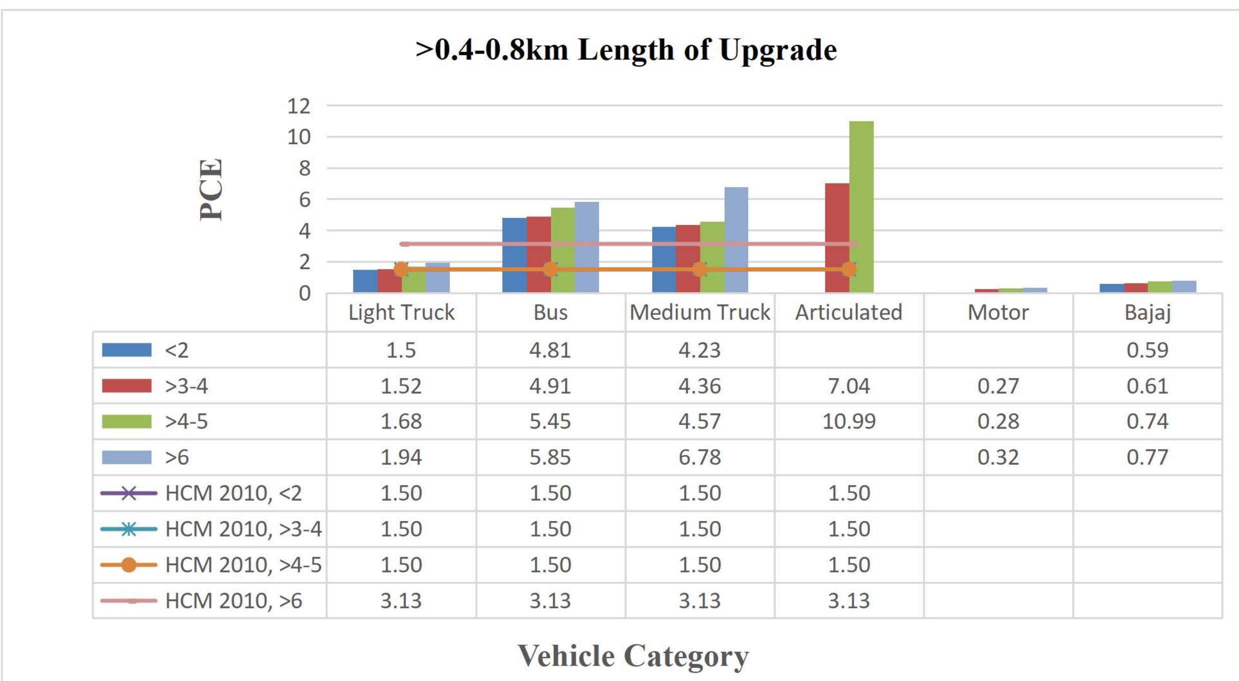
Figure 4.23 Variation of PCE values with vehicle category, for 0-0.4km length of upgrade using simulation

In Figure 4.24 and Figure 4.25, the correlation between PCE values and vehicle categories for a length of upgrade ranging from >0.4 to 0.8 kilometers is illustrated. The figures reveal a notable rise in PCE value as the size of the vehicle increases. Notably, the PCE values obtained from field research and simulation result surpass those obtained from HCM 2010, with the exception of light trucks. This distinction can be attributed to considerable variations in local conditions.



	Light Truck	Bus	Medium Tru ck	Articulated	Motor	Bajaj
<2	1.44	4.26	3.96			0.58
>3-4	1.47	4.48		7.89	0.26	0.68
>4-5	1.64	4.71	4.27		0.34	0.7
>6	1.7	5.05	4.56			0.8
HCM 2010,<2	1.50	1.50	1.50	1.50		
HCM 2010, >3-4	1.81	1.81	1.81	1.81		
HCM 2010, >4-5	2.19	2.19	2.19	2.19		
HCM 2010, >6	3.13	3.13	3.13	3.13		

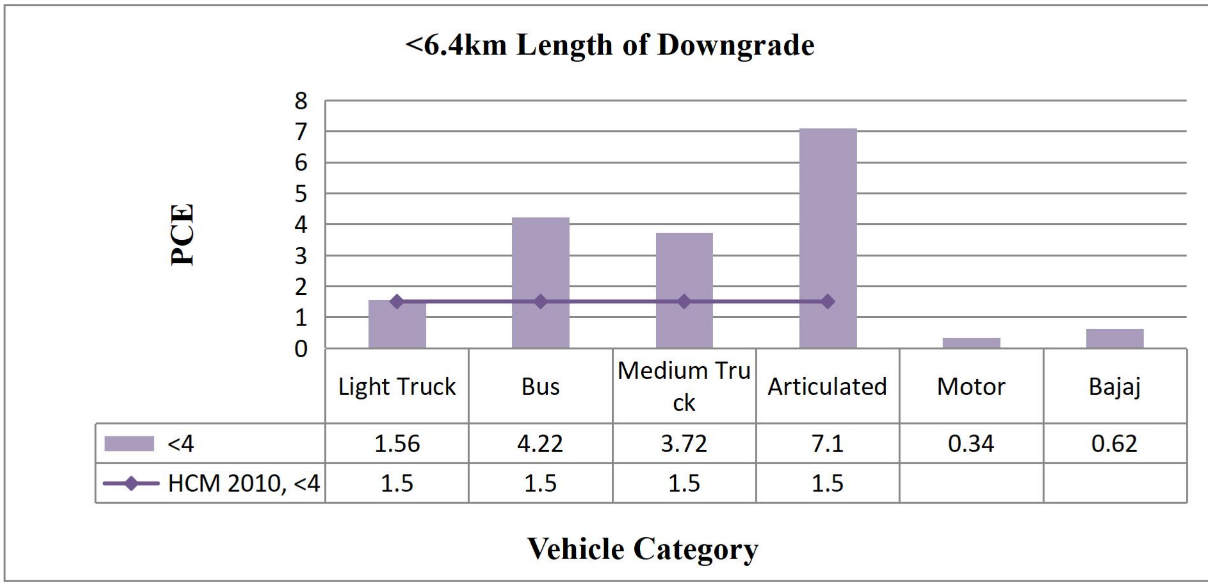
Figure 4.24 Variation of PCE values with vehicle category, for >0.4-0.8km length of upgrade



	Light Truck	Bus	Medium Truck	Articulated	Motor	Bajaj
<2	1.5	4.81	4.23			0.59
>3-4	1.52	4.91	4.36	7.04	0.27	0.61
>4-5	1.68	5.45	4.57	10.99	0.28	0.74
>6	1.94	5.85	6.78		0.32	0.77
HCM 2010, <2	1.50	1.50	1.50	1.50		
HCM 2010, >3-4	1.50	1.50	1.50	1.50		
HCM 2010, >4-5	1.50	1.50	1.50	1.50		
HCM 2010, >6	3.13	3.13	3.13	3.13		

Figure 4.25Variation of PCE values with vehicle category, for >0.4-0.8km length of upgrade using simulation

The variation of PCE values with vehicle category for a length of downgrade of less than 6.4 km is shown in Figure 4.26 and Figure 4.27. From these figures, it is evident that the PCE values obtained from the HCM 2010 are consistently smaller compared to the calculated values, and this difference becomes more pronounced as the size of the vehicle increases.



Fi

gure 4.26 Variation of PCE values with vehicle category, for <6.4km length of downgrade

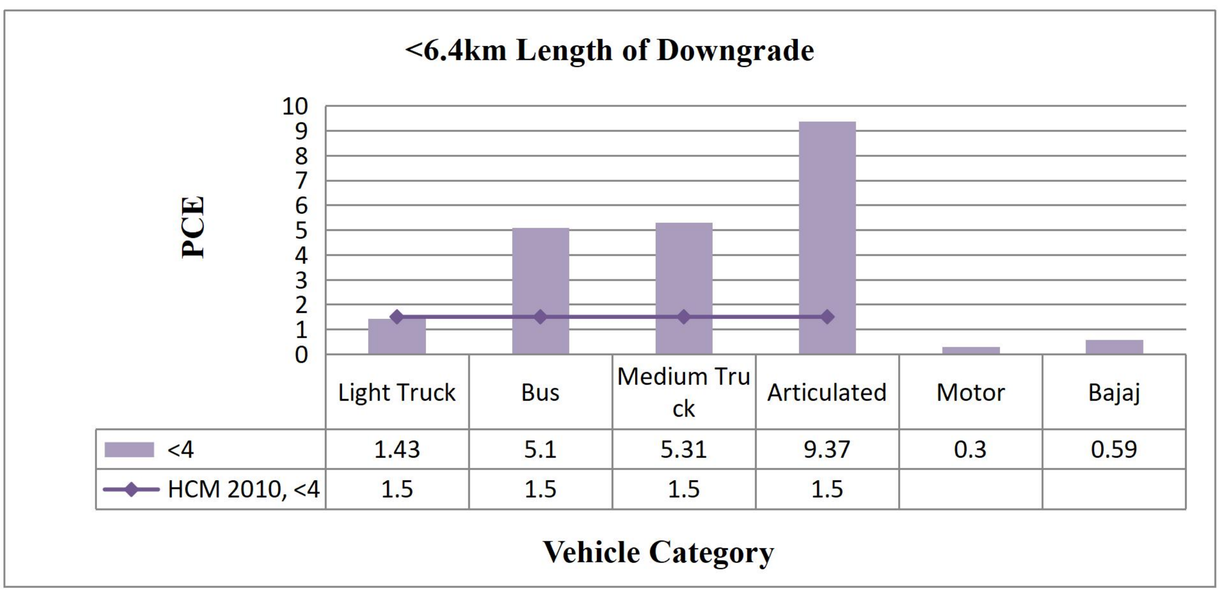


Figure 4.27 Variation of PCE values with vehicle category, for <6.4km length of downgrade using simulation

4.2.5 Variation of PCE Values with method of analysis

This subsection presents the variation of PCE values based on different methods of investigation. Specifically, the figures below illustrate the PCE values obtained through the speed area method of investigation using field data and simulation results for various vehicle categories.

In addition, when looking at the figures below, it is evident that the PCE values obtained from the simulation generally tend to be slightly higher compared to the speed area method using field data. This discrepancy can be attributed to the default values utilized during the modeling of the simulation. This trend has occurred in other similar researches (Addisu, 2021).

The variation of PCE values with different methods of investigation for a grade length of 0 to 0.4km and a percentage of grades exceeding 2% is depicted in Figure 4.28. Based on the figure, it is evident that there is a slight disparity between the PCE values obtained from both methods of investigation.

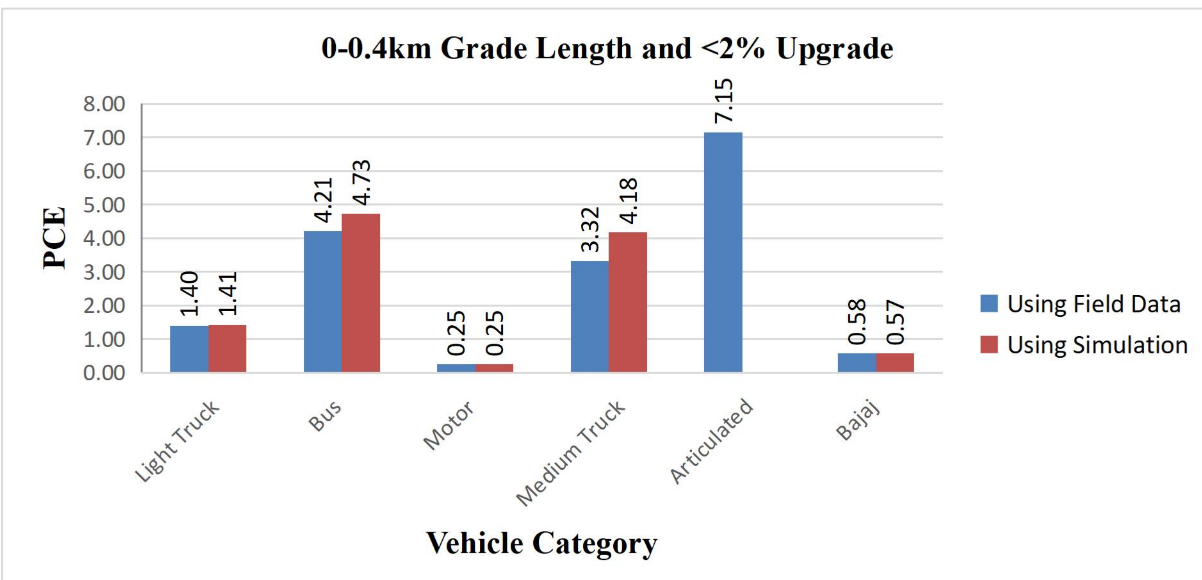


Figure 4.28 Variation of PCE values with method of analysis, for 0-0.4km grade length and <2% upgrade

In Figure 4.29, the variation of PCE values with different methods of investigation for a grade length of 0 to 0.4km and a percentage of grades exceeding 3% to 4% is depicted.

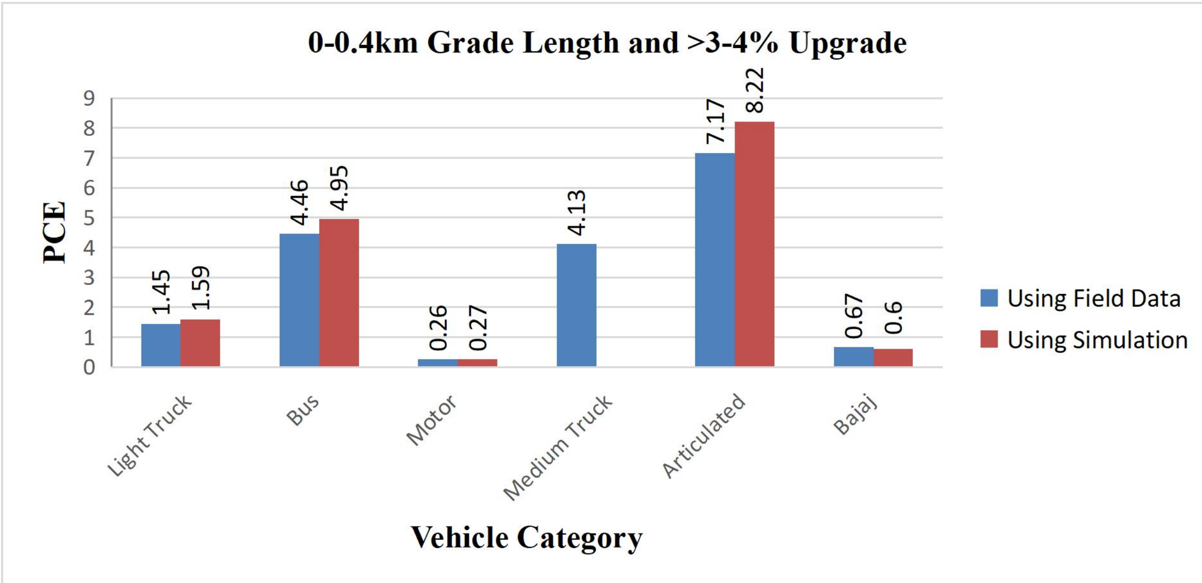


Figure 4.29 Variation of PCE values with method of analysis, for 0-0.4km grade length and >3-4% upgrade

The impact of employing different methods of investigation for a grade length ranging from 0 to 0.4km and an upgrade of more than 4% to 5% is shown in figure 4.30. The PCE values obtained from simulation are generally higher compared to those derived from field investigation, with the exception of Articulated Vehicles.

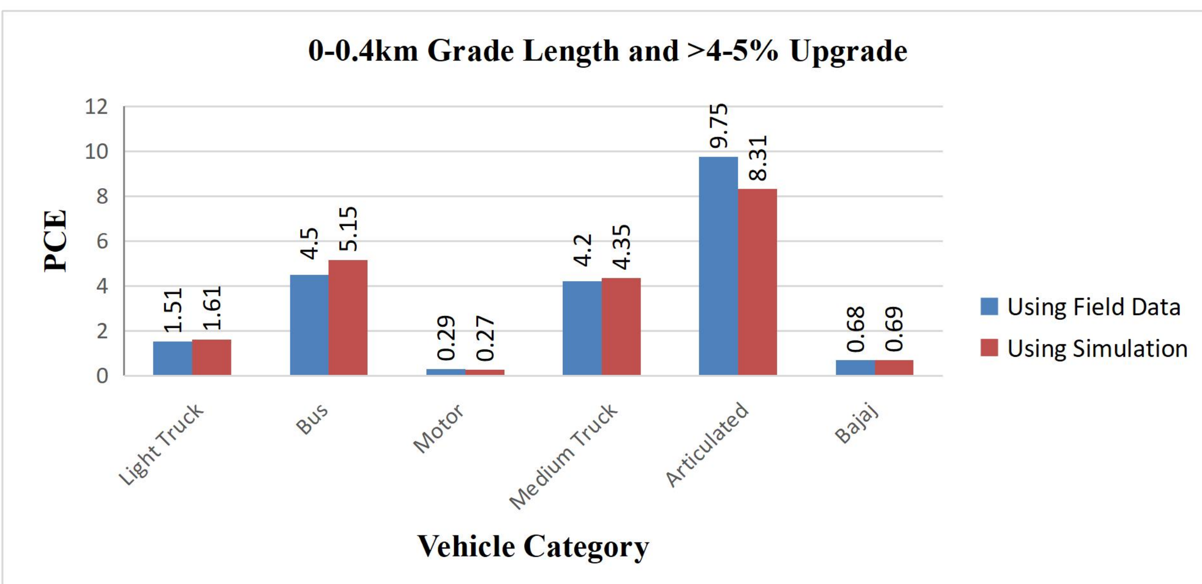


Figure 4.30 Variation of PCE values with method of analysis, for 0-0.4km grade length and >4-5% upgrade

In Figure 4.31, the variation of PCE values with different methods of investigation for a grade length more than 0.4km to 0.8km and a percentage of grades exceeding less than 2% is depicted.

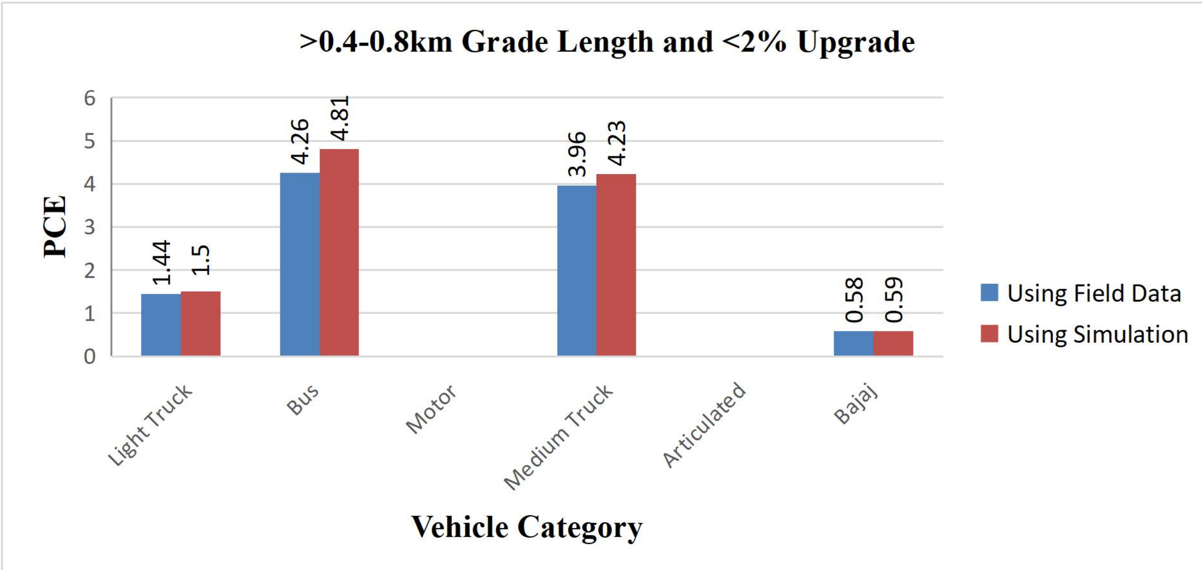


Figure 4.31 Variation of PCE values with method of analysis, for >0.4-0.8km grade length and <2% upgrade

The impact of employing different methods of investigation for a grade length ranging more than 0.4km to 0.8km and an upgrade of more than 3% to 4% is shown in figure 4.32. The PCE values obtained from simulation are generally higher compared to those derived from field investigation, with the exception of Articulated Vehicles.

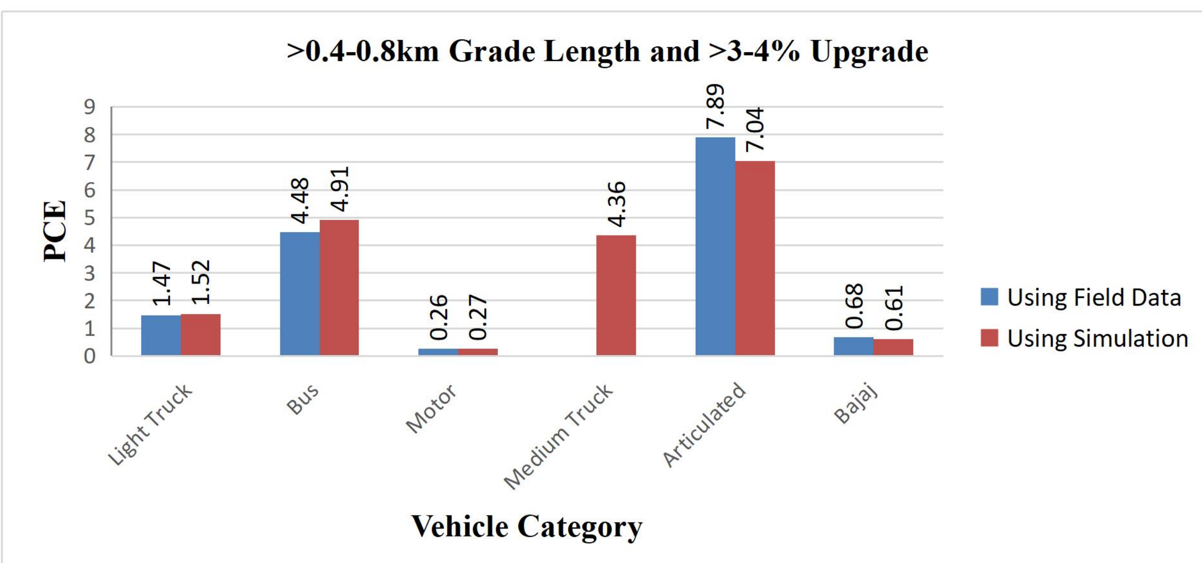


Figure 4.32 Variation of PCE values with method of analysis, for >0.4-0.8km grade length and >3-4% upgrade

Figure 4.33 displays the variation of PCE values for different vehicle categories using both the speed area method and the simulation method of investigation. The analysis focuses on a grade length ranging from more than 0.4km to 0.8km with an upgrade of more than 4-5%.

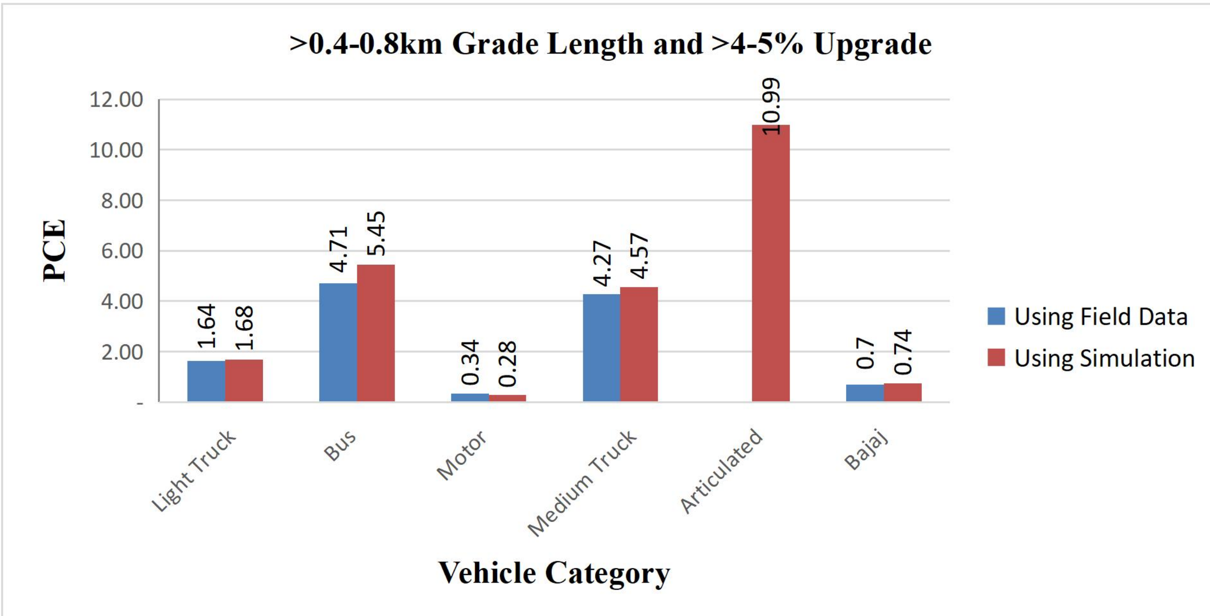


Figure 4.33 Variation of PCE values with method of analysis, for >0.4-0.8km grade length and >4-5% upgrade

Figure 4.34 displays the variation of PCE values for different vehicle categories using both the speed area method and the simulation method of investigation. The analysis focuses on a grade length ranging from more than 0.4km to 0.8km with an upgrade of more than 6%. The figure highlights that the simulation method generally produces higher PCE values compared to the speed area method using field data with the exception for Bajaj.

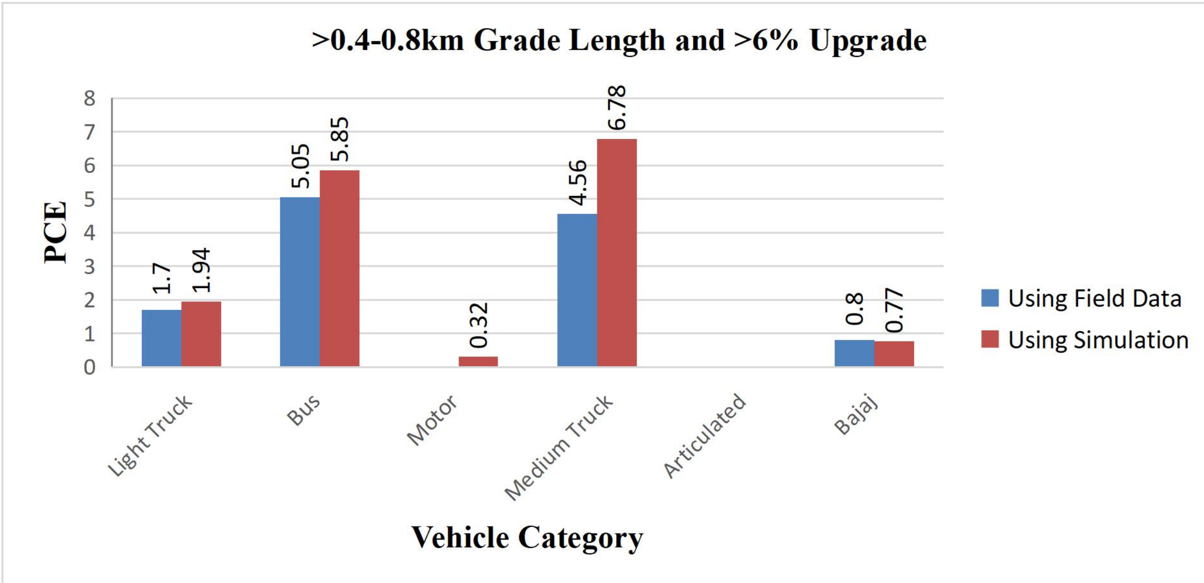


Figure 4.34 Variation of PCE values with method of analysis, for >0.4-0.8km grade length and >6% upgrade

Figure 4.35 displays the variation of PCE values for different vehicle categories using both the speed area method and the simulation method of investigation. The analysis focuses on a grade length less than 6.4km with a downgrade less than 4%.

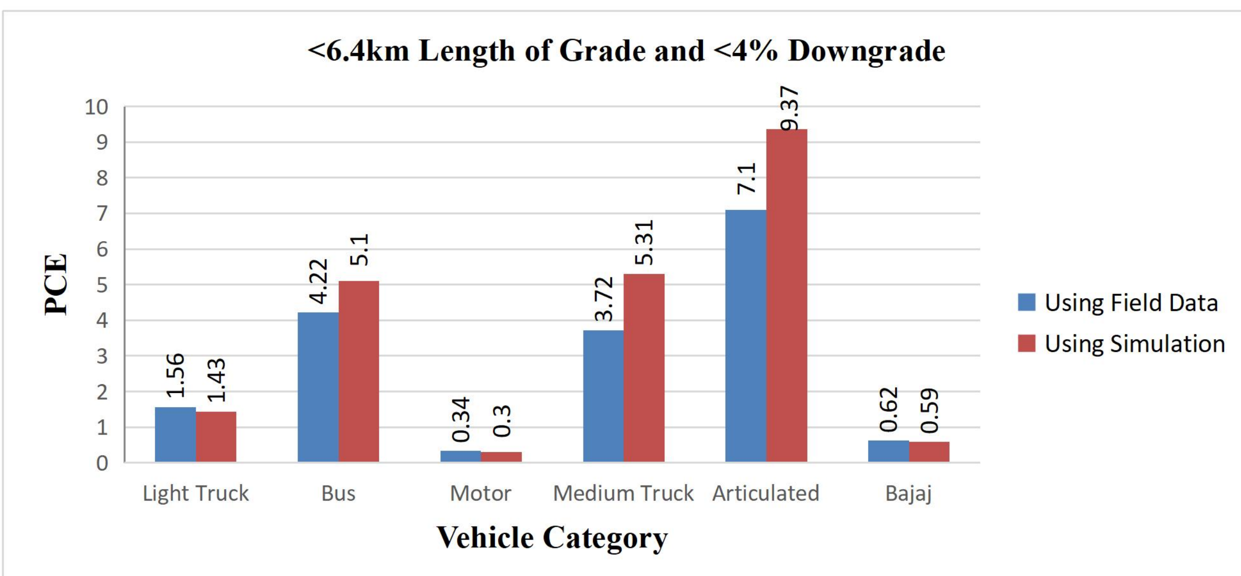


Figure 4.35 Variation of PCE values with by method of analysis, for <6.4km grade length and <4% downgrade

4.3 Proposed PCE Values

Summarizing the above discussions, this subsection presents summary of proposed PCE values using simulation, flow density method and speed area method of investigation.

Table 4.1 and table 4.2 displays the PCE values corresponding to different vehicle categories, percent grades, and lengths of grades.

Table 4.1 Proposed PCE values for upgrades using Simulation method

Percent Upgrade	Length (km)	PCE					
		Light Truck	Bus	Motor	Medium Truck	Articulated	Bajaj
1.46	0-0.4	1.41	4.73	0.25	4.18		0.57
	0.4-0.8	1.45	4.8	0.26	4.2		0.59
	0.8-1.2	1.49	4.82	0.27	4.24		0.6
	>1.2	1.49	4.83	0.28	4.39		0.63
1.85	0-0.4	1.49	4.78		4.22		0.59
	0.4-0.8	1.5	4.81		4.23		0.6
	0.8-1.2	1.5	4.85		4.28		0.62
	>1.2	1.52	4.93		4.44		0.63
3.2	0-0.4	1.5	4.89	0.26	4.28	7.02	0.6
	0.4-0.8	1.52	4.91	0.27	4.36	7.04	0.61
	0.8-1.2	1.58	4.93	0.27	4.38	7.13	0.62
	>1.2	1.63	5.01	0.28	4.52	7.26	0.64
3.97	0-0.4	1.59	4.95	0.27		8.22	0.6
	0.4-0.8	1.63	4.97	0.27		8.31	0.62
	0.8-1.2	1.64	5.13	0.28		8.31	0.62
	>1.2	1.68	5.16	0.29		8.55	0.65
4.01	0-0.4	1.61	5.15	0.27	4.35	8.31	0.69
	0.4-0.8	1.64	5.19	0.28	4.4	8.69	0.71
	0.8-1.2	1.67	5.2	0.28	4.51	8.75	0.72
	>1.2	1.71	5.26	0.29	4.55	9.11	0.75
4.4	0-0.4	1.64	5.26	0.28	4.51	8.76	0.72
	0.4-0.8	1.68	5.45	0.28	4.57	10.99	0.74
	0.8-1.2	1.69	5.58	0.28	4.7	10.99	0.75
	>1.2	1.81	5.9	0.3	4.89	11.47	0.76
7.5	0-0.4	1.8	5.57	0.28	6.45		0.75
	0.4-0.8	1.94	5.85	0.32	6.78		0.77
	0.8-1.2	1.96	5.86	0.32	6.86		0.77
	>1.2	1.99	5.99	0.32	7		0.78

In Table 4.2, a summary of the proposed PCE (Passenger Car Equivalent) values is presented for different vehicle categories, specifically for conditions of <4% downgrade and <6.4km length of grade.

Table 4.2 Proposed PCE values for downgrades using Simulation method

Percent Downgrade	**Length (km)**	**PCE**					
		Light Truck	**Bus**	**Motor**	**Medium Truck**	**Articulated**	**Bajaj**
<4	<6.4	1.43	5.1	0.3	5.31	9.37	0.59

Table 4.3 and table 4.4 presents a comprehensive overview of the suggested PCE values for different heavy vehicle compositions, taking into account percent grade of the road and its length.

Table 4.3 Proposed PCE values for upgrades using Flow density method

Percent Upgrade	**Length of Grade (km)**	**% Heavy Vehicles**							
		4%	**5%**	**6%**	**8%**	**10%**	**15%**	**20%**	**25%**
>6	0.4-0.8	12.83	11.6	10.94	7.8	7.56	5.8	4.53	3.9
>4	0.4-0.8			7.9	7.8	6.4	4.7	4.09	3.5
	0-0.4	7.9	7.75	7.26	6.2	5.2	4.58	4.01	3
>3-4	0.4-0.8	7.84	7.67	7.19	5.42	4.8	4.25	3.89	2.25
<2	0-0.4	6.3	6.19	5.93	4.72	3.61	3.34	1.7	1.21
	0.4-0.8	6.62	6.36	5.99	5.31	4.8	3.63	2.25	2.25

Table 4.4 Proposed PCE values for downgrades using Flow density method

Percent Downgrade	Length of Grade (km)	**%Heavy Vehicles**			
		5%	10%	15%	20%
<4	<6.4	4.5	3.73	3.66	3.31

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the findings of this study, it can be concluded that the PCE values provided in HCM 2010 for multilane highways are not consistent with the local conditions of multilane highways (Arterials) in Addis Ababa. Therefore, it is necessary to determine local PCE values specific to the area.

Based on the findings of this study, it can be concluded that the PCE values provided in HCM 2010 for multilane highways are not consistent with the local conditions of multilane highways (Arterials) in Addis Ababa. This local conditions are difference in the characteristics of the surrounding area, difference in characteristics of the road and change in drivers' behaviour. Therefore, it is necessary to determine local PCE values specific to the area.

Recognizing the inconsistency of using PCE values from HCM 2010 in local conditions, this study employs different investigation methods such as the Flow Density Method, Speed Area Method, and Simulation to determine local PCE values. By utilizing these different methods, a comprehensive understanding of the PCE values in the local context is achieved and local PCE values are proposed.

The significant variation of proposed PCE values compared to those in the HCM 2010 is worthy of note, particularly when the percentage composition of heavy vehicles decreases. This implies that as the maximum effect of heavy vehicles increases, the impact of using excessively small PCE values becomes apparent. Consequently, using PCE values that are too small can lead to the underestimation of traffic impacts, the overestimation of capacity, the design of inefficient road pavements, and inaccurate analysis and estimation of costs. Hence, it is crucial to emphasize that major problems related to roads and transportation in the country, such as low level of road service and pavement distresses occurring before the design period, should be reassessed and analyzed using appropriate PCE values.

5.2 RECOMMENDATIONS

- The PCE values determined in this study exhibit significant differences when compared to the values provided in HCM 2010. As a result, it is highly recommended that local traffic engineers utilize the PCE values derived from this study. These values have been specifically tailored to the local conditions and characteristics of the multilane highways in Addis Ababa. By using these locally determined PCE values, traffic engineers can make more accurate assessments and informed decisions regarding the capacity and performance of the road network.

Recommendation for future researchers

- This study only considers clear whether condition. Hence further studies shall be conducted considering different weather conditions.
- Further studies shall be conducted considering different level of services.
- Further studies can be conducted by considering different multilane highways with different road way characteristics such as for undivided multilane highways and multilane highways with significant access.

References

Addis Ababa City Roads Authority (2020). *Road inventory report.* Addis Ababa City Roads Authority

Addis Ababa city roads authority (AACRA) geometric design manual (2004, page 7-17). Addis Ababa City Roads Authority. Addis Ababa

Addisu, T. (2021). *Passenger car equivalent for capacity analysis on multilane highways in Addis Ababa* [Master's thesis, Addis Ababa Science and Technology University].

Ahmed, A., Younghan, J., and Hesham, R. (2005). Developing Passenger Car Equivalency Factors for Heavy Vehicles during Congestion. *Journal of transportation engineering, ASCE.*
doi: 10.1061/~ASCE!0733-947X~2005!131:7~514!

A. Mehar., S. Chandra., & S. Velmurugan (2014). Passenger Car Units at Different Levels of Service for Capacity Analysis of Multilane Interurban Highways in India. *Journal of Transportation Engineering* 2014.140:81-88

André, L., & José, R. (2011). Truck Equivalence Factors for Divided, Multilane Highways in Brazil. *Published by Elsevier Ltd. Stockholm, Sweden.* doi:10.1016/j.sbspro.2011.04.447

Ararsa, B. (2020). *Capacity and Passenger Car Unit Estimation for Heterogeneous Traffic Stream of Trunk Roads* [Master's thesis, Addis Ababa Institute of Technology]. www.aait.edu.et

Box, P.C., and Oppenlander J,C. (1976). Manual of Traffic Engineering Studies, 4th ed. *Institute of Transportation Engineers.* Washington, D.C., USA.

Eshetu. Z., & Mengistu. M. (2020). Estimation of Passenger Car Units for Different Category of Vehicles in Midblock. *World Academics Journal of Engineering Sciences*. Vol.7. www.isroset.org

Florida Department of Transportation (FDOT) (2021). Traffic Analysis Handbook. Florida department of transportation, System implementation office.

Girum, T. (2016). *Passenger car equivalents for basic freeway segments on Addis Ababa – Adama expressway* [Master's thesis, Addis Ababa Institute of Technology]. www.aait.edu.et

Helen, H. (2020). Determination of Passenger Car Unit for Urban Roads: A Case Study in Addis Ababa. *American Journal of Construction and Building Materials*. doi: 10.11648/j.ajcbm.20210502.13

Highway Capacity Manual (HCM) (2010). Transportation Research Board. Washington, DC.

Highway Capacity Manual (HCM) (1965). Transportation Research Board. Washington, DC.

Kanakabandi. S., & Brind. K., (2014). Estimation of the Passenger Car Equivalent: A Review. *International Journal of Emerging Technology and Advanced Engineering.* Volume 4. www.ijetae.com

Michael, A. (2019). *Through traffic passenger car equivalents for selected signalized intersections in Addis Ababa, Ethiopia* [Master's thesis, Addis Ababa Institute of Technology]. www.aait.edu.et

Muhammad, A. (2013). Passenger Car Equivalent Factors in Heterogeneous Traffic Environment-Are We Using the Right Numbers?. *Published by Elsevier.* doi: 10.1016/j.proeng.2014.07.004

Oppenlander, J.C. (1963). Sample Size Determination for Spot-Speed Studies at Rural, Intermediate, and Urban Locations. *Journal of the Highway Research Board.* No. 35, HRB, Washington, D.C.

Pajecki, R., Ahmed, F., Qu, X. et al (2019). Estimating passenger car equivalent of heavy vehicles at roundabout entry using micro-traffic simulation. *Frontiers in Built Environment, 5.* http://dx.doi.org/10.3389/fbuil.2019.00077

Pan, L., Zijian, Z., Denver, T., & Danguang, P. (2020). Measuring Passenger Car Equivalents (PCE) for Heavy Vehicle on Two Lane Highway Segments Operating Under Various Traffic Conditions. *Journal of Advanced Transportation. Vol. 2020, Article ID 6972958, 9 pages, 2020*. https://doi.org/10.1155/2020/6972958

Parthia, S., H. M. Iqbal, M., DR. Quazi, S., & MD. Zahurul, I. (2009). Passenger car equivalent (PCE) of through vehicles at signalized intersections in Dhaka metropolitan city, Bangladesh. *IATSS Research Vol.33 No.2.*

Robertson, H.D. (1994). ITE Manual of Transportation Engineering Studies. Prentice Hall, Englewood Cliffs, N.J.

Roger, P. R., Elena S. P., William R. M. (2011). *Traffic Engineering* (4th ed).
ISBN-13:978-0-13-613573-9 (alk. paper)
ISBN-10: 0-13-613573-0 (alk. paper)

Seelam, S., & Arpan, M. (2017). A modified approach for estimation of passenger car units on intercity divided multilane highways**.** *Archives of transport volume 42.* doi: 10.5604/01.3001.0010.0528

Syed, O. B. (2020). Passenger Car Equivalent Estimation Methods of Trucks in Traffic Stream. *International Journal of Recent Technology and Engineering.* (IJRTE) ISSN: 2277-3878, Volume-8 Issue-5

Tanaboriboon, Y., & Aryal, R. (1990). Effect of vehicle size on highway capacity in Thailand. *Journal of Transportation Engineering.* doi: 10.1061/(ASCE)0733-947X(1990)116:5(658)

Wiley D, C., & Carroll J, M. (1983). Passenger-Car Equivalents for Rural Highways. *Transportation Research Record 905*

Yonas, A. (2020, September 26). Registered vehicle in Ethiopia reaches 1.2 mln. *The Reporter.* (26th September 2020). https://www.thereporterethiopia.com/article/registered-vehicle-ethiopia-reaches

Zhou, J., Rilett, L., & Jones, E. (2019). Estimating Passenger Car Equivalent using the HCM-6 PCE Methodology on Four-Lane Level Freeway Segments in Western U.S. *Transportation Research Record*, *2673(11), 529-545*. https://doi.org/10.1177/0361198119851448

Appendix A

Outer Ring Road Profile Data

Outer ring road profile data (Right Frontage Way)						
No.	**Chainage**		**Grade (%)**	**Curve type**	**Length of grade (m)**	**Location selected for**
	Start	**End**				
1	0+098.710	0+221.117	0.322	Crest	122.407	
2	0+221.117	0+657.549	-0.7	Sag	436.432	
3	0+657.549	1+190.974	2.491	Crest	533.425	
4	1+190.974	1+610.000	1.735	Crest	419.026	
5	1+610.000	1+895.000	-0.96	Sag	285	
6	1+895.000	2+220.000	-4.256	Sag	325	
7	2+220.000	2+880.000	-7.5	Sag	660	
8	2+880.000	3+080.000	-3.5	Sag	200	
9	3+080.000	3+740.000	-6.9	Sag	660	
10	3+740.000	4+040.000	-4	Sag	300	
11	4+040.000	4+340.000	-0.3	Sag	300	
12	4+340.000	4+830.878	3.962	Crest	490.878	
13	4+830.878	5+582.200	-3.994	Sag	751.322	
14	5+582.200	6+145.000	0.388	Crest	562.8	
15	6+145.000	6+525.000	-2.525	Sag	380	
16	6+525.000	6+893.703	0.706	Crest	368.703	
17	6+893.703	7+684.754	-1.69	Sag	791.051	
18	7+684.754	9+273.140	-0.3	Sag	1588.386	
19	9+273.140	10+000.000	-1.495	Sag	726.86	
20	10+000.000	10+415.000	-0.3	Sag	415	
21	10+415.000	11+425.000	0.3	Crest	1010	

22	11+425.000	11+915.000	1.391	Crest	490	
23	11+915.000	12+521.301	0.5	Crest	606.301	
24	12+521.301	12+826.351	3.952	Crest	305.05	
25	12+826.351	13+175.382	-2.343	Sag	349.031	
26	13+175.382	13+608.071	1.982	Crest	432.689	
27	13+608.071	13+719.153	1.975	Crest	111.082	
28	13+719.153	13+843.546	2.118	Crest	124.393	
29	13+843.546	14+320.000	4.914	Crest	476.454	
30	14+320.000	15+069.948	1.507	Crest	749.948	
31	15+069.948	15+218.895	4.985	Crest	148.947	
32	15+218.895	15+543.333	4.985	Crest	324.438	
33	15+543.333	15+840.215	3.97	Crest	296.882	0-0.4km Length of Upgrade
34	15+840.215	16+196.020	-3.35	Sag	355.805	
35	16+196.020	16+485.001	-0.3	Sag	288.981	
36	16+485.001	16+855.000	3.2	Crest	369.999	
37	16+855.000	17+610.000	-1.868	Sag	755	
38	17+610.000	18+325.000	-1.151	Sag	715	
39	18+325.000	18+830.000	3.82	Crest	505	
40	18+830.000	19+435.000	3.1	Crest	605	
41	19+435.000	19+786.233	1.46	Crest	351.233	0-0.4km Length of Upgrade
42	19+786.233	20+265.000	2.057	Crest	478.767	
43	20+265.000	20+795.000	-2.9	Sag	530	
44	20+795.000	21+215.000	0.3	Crest	420	
45	21+215.000	21+805.000	4	Crest	590	
46	21+805.000	22+881.453	-0.8	Sag	1076.453	0-6.4km Length of Downgrade
47	22+881.453	23+786.422	3.2	Crest	904.969	0.8-1.2km Length of Upgrade
48	23+786.422	24+651.422	-3.88	Sag	865	

49	24+651.422	25+151.422	5.4	Crest	500	
50	25+151.422	25+721.422	4.4	Crest	570	
51	25+721.422	26+610.000	0.394	Crest	888.578	
52	26+610.000	26+960.000	-4.538	Sag	350	
53	26+960.000	27+273.683	-0.304	Sag	313.683	
54	27+273.683	27+475.000	4.055	Crest	201.317	0-0.4km Length of Upgrade
55	27+475.000	28+100.830	2.84	Crest	625.83	
Outer ring road profile data (Left Frontage Way)						
No.	**Chainage**		**Grade (%)**	**Curve type**	**Length of grade (m)**	**Location selected for**
	Start	**End**				
1	0+127.272	0+297.098	0.309	Crest	169.826	
2	0+297.098	0+718.417	-0.7	Sag	421.319	
3	0+718.417	1+220.000	2.79	Crest	501.583	
4	1+220.000	1+698.999	1.283	Crest	478.999	
5	1+698.999	1+960.766	-2.106	Sag	261.767	
6	1+960.766	2+300.000	-4.26	Sag	339.234	
7	2+300.000	2+960.000	-7.5	Sag	660.000	0-0.4km Length of Downgrade
8	2+960.000	3+165.000	-3.5	Sag	205.000	
9	3+165.000	3+780.000	-6.9	Sag	615.000	
10	3+780.000	4+009.000	-4	Sag	229.000	
11	4+009.000	4+355.000	-0.3	Sag	346.000	
12	4+355.000	4+841.865	3.809	Crest	486.865	
13	4+841.865	5+625.331	-3.994	Sag	783.466	
14	5+625.331	6+200.000	0.72	Crest	574.669	
15	6+200.000	6+520.000	-2.28	Sag	320.000	
16	6+520.000	6+900.000	0.3	Crest	380.000	0-0.4km Length of Upgrade
17	6+900.000	7+752.665	-1.847	Sag	852.665	0-0.4km Length of Downgrade

18	7+752.665	8+000.000	-0.3	Sag	247.335	
19	8+000.000	9+273.141	-0.3	Sag	1273.141	
20	9+273.141	10+000.000	-1.495	Sag	726.859	
21	10+000.000	10+415.000	-0.3	Sag	415.000	
22	10+415.000	11+410.000	0.3	Crest	995.000	0.8-1.2km Length of Upgrade
23	11+410.000	11+957.221	1.356	Crest	547.221	
24	11+957.221	12+487.957	0.5	Crest	530.736	
25	12+487.957	12+790.000	3.89	Crest	302.043	
26	12+790.000	13+140.000	-2.234	Sag	350.000	
27	13+140.000	13+565.123	1.946	Crest	425.123	
28	13+565.123	13+677.453	1.906	Crest	112.330	
29	13+677.453	14+055.000	3.574	Crest	377.547	
30	14+055.000	14+260.000	4.82	Crest	205.000	
31	14+260.000	14+705.000	1.32	Crest	445.000	

Appendix B

Sample Calculations

- PCE by speed area method using field data

Data collection point at 6+550

Point selected for <4% downgrade with 0-0.4km length of grade

Description	Car	Bajaj	Bus	Light Truck	Articulated	Motor	Medium Truck
No	258	8	14	11	1	1	2
Average travel speed, km/hr	50.43	41.13	45.37	45.77	41.48	52.60	39.09
Average travel time,hr	0.000477	0.000586	0.000547	0.000522	0.000554	0.000437	0.000615
Average travel time,sec	1.72	2.11	1.97	1.88	2.00	1.57	2.21
Vehicle composition,%	0.87	0.03	0.05	0.04	0.00	0.00	0.01
Average dimension, m2	7.54	3.63	28.18	10.00	43.73	1.72	21.48
Vc/Vi	1.00	1.23	1.11	1.10	1.22	0.96	1.29
Ac/Ai	1.00	2.08	0.27	0.75	0.17	4.38	0.35
PCE = Vc/Vi/Ac/Ai	1.00	0.59	4.16	1.46	7.05	0.22	3.68

Vc/Vi for Car=	Average speed of car/Average speed of car	Ac/Ai for Car=	Average dimension of car/Average dimension of car	PCE_{car}=	Vc/Vi/Ac/Ai
.=	50.43/50.43	.=	7.54/7.54	.=	1.00/1.00
.=	1.00	.=	1.00	.=	1.00
Vc/Vi for Bajaj=	Average speed of car/Average speed of Bajaj	Ac/Ai for Bajaj=	Average dimension of car/Average dimension of Bajaj	PCE_{Bajaj}=	Vc/Vi/Ac/Ai
.=	50.43/41.13	.=	7.54/3.63	.=	1.23/2.08
.=	1.23	.=	2.08	.=	0.59
Vc/Vi for Bus=	Average speed of car/Average speed of Bus	Ac/Ai for Bus=	Average dimension of car/Average dimension of Bus	PCE_{Bus}=	Vc/Vi/Ac/Ai
.=	50.43/45.37	.=	7.54/28.18	.=	1.11/0.27
.=	1.11	.=	0.27	.=	4.16
Vc/Vi for LT=	Average speed of car/Average speed of LT	Ac/Ai for LT=	Average dimension of car/Average dimension of LT	PCE_{LT}=	Vc/Vi/Ac/Ai

.=	50.43/45.76	.=	7.54/10	.=	1.1/0.75
.=	1.10	.=	0.75	.=	1.46
Vc/Vi for Articulated=	Average speed of car/Average speed of Articulated	Ac/Ai for Articulated=	Average dimension of car/Average dimension of Articulated	$PCE_{Articulated}$=	Vc/Vi/Ac/Ai
.=	50.43/41.48	.=	7.54/43.73	.=	1.22/0.17
.=	1.22	.=	0.17	.=	7.05
Vc/Vi for Motor=	Average speed of car/Average speed of Motor	Ac/Ai for Motor=	Average dimension of car/Average dimension of Motor	PCE_{Motor}=	Vc/Vi/Ac/Ai
.=	50.43/52.60	.=	7.54/1.72	.=	0.96/4.38
.=	0.96	.=	4.38	.=	0.22
Vc/Vi for MT=	Average speed of car/Average speed of MT	Ac/Ai for MT=	Average dimension of car/Average dimension of MT	PCE_{MT}=	Vc/Vi/Ac/Ai
.=	50.43/39.08	.=	7.54/21.48	.=	1.29/0.35
.=	1.29	.=	0.35	.=	3.68

- PCE by flow rate and density method using field data

Data collection point at 6+550

Point selected for <4% downgrade with 0-0.4km length of grade

$$E_T = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1$$

For base flow rate, data was extracted form 10:38.724 to 12:09.943am which is equal to 1.52minutes. In addition, the number of passenger cars was counted to be 34. Hence the base flow rate for 15min interval was calculated as:

1.52min =	34 cars
15min=	X
x=q_B	336

Data collection time interval		02:04.068	09:56.627 12:00.695	Pi=	0.06
Car					
2.0679min=	37 cars				
15 min=	c				
	c=	254	269= q_M		
Heavy vehicles					
2.0679min=	2 vehicles				
15 min=	h				
	h=	15			
ET=PCE=	**5.15**				
		01:39.492	10:38.975 12:18.467	Pi=	0.06
Car					
1.7min=	34 cars				
15 min=	c				
	c=	300			
Heavy vehicles					
1.7min=	2 vehicles		318= q_M		
15 min=	h				
	h=	18			
ET=PCE=	**1.9**				
Taking average of the two PCE values, (5.15+1.9)/2, PCE =4.06 for 5% heavy vehicle composition					

		04:30.037	00:01.154 04:31.191	Pi=	0.11
Car					
4.5min=	55 cars				
15 min=	c				
	c=	183			
Heavy vehicles					
4.5min=	7 vehicles		206= q_M		
15 min=	h				
	h=	23			
ET=PCE=	**6.7**				

		00:52.470	06:39.657 07:32.127	Pi=	0.1
Car					
0.876min=	18 cars				
15 min=	c				
	c=	183			
Heavy vehicles					
0.876min=	2 vehicles		206= q_M		
15 min=	h				
	h=	23			
ET=PCE=	**0.8**				

		01:36.716	03:47.460 05:24.176	Pi=	0.1
Car					
1.613min=	27 cars				
15 min=	c				
	c=	251			
Heavy vehicles					
1.613min=	3 vehicles		279= q_M		
15 min=	h				
	h=	28			
ET=PCE=	**3.04**				

Taking average of the three PCE values, (6.7+0.8+3.04)/3, PCE =3.53 for 10% heavy vehicle composition

		01:01.363	08:55.366 09:56.729	Pi=	0.16			01:21.359	01:03.517 02:24.876	Pi=	0.15
Car						Car					
1.0228min=	16 cars					1.357min=	17 cars				
15 min=	c					15 min=	c				
	c=	235					c=	188			
Heavy vehicles			279= q_M			Heavy vehicles			221= q_M		
1.0228min=	3 vehicles					1.357min=	3 vehicles				
15 min=	h					15 min=	h				
	h=	44					h=	33			
ET=PCE=	**2.28**					**ET=PCE=**	**4.5**				
Taking average of the two PCE values, (2.28+4.5)/2, PCE =3.37 for 15% heavy vehicle composition											

		01:37.220	01:01.018 02:38.238	Pi=	0.16
Car					
1.621min=	20 cars				
15 min=	c				
	c=	185			
Heavy vehicles			231= q_M		
1.621min=	5 vehicles				
15 min=	h				
	h=	46			
ET=PCE=	**3.27**				

Appendix C

Simulation Output

4.01%	27+475.000						
0-0.4km at 380m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.785	57.4475	51.4675	55.49	41.4975	43.95333333	50.8925
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.145132512	1.278185263	1.185528924	1.585276221	1.496701047	1.292626615
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.52	4.78	0.27	4.52	8.69	0.62
0.4-0.8km at 700	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	64.8075	57.2475	50.435	60.3725	42.1675	42.94	49.2425
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.132058168	1.284970754	1.073460599	1.536906385	1.509257103	1.316088744
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.5	4.81	0.25	4.38	8.76	0.63
0.8-1.2 at 1100	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.1375	52.8975	50.205	55.77	42.5825	41.49	51.7475
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.231390897	1.297430535	1.167966649	1.529677684	1.569956616	1.258756462
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.63	4.85	0.27	4.36	9.11	0.61
>1.2km at 1.7km	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.1225	54.6925	48.5675	52.545	43.3575	43.17	51.9775
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63

Vc/Vi	1	1.190702564	1.340865805	1.239366257	1.501989275	1.508512856	1.252897889
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.58	5.01	0.28	4.28	8.75	0.6

-0.30%	6+550						
0-0.4km at 380m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	76.765	69.3225	52.53	48.77333333	37.61	44.03	61.445
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.107360525	1.461355416	1.573913341	2.0410795	1.743470361	1.249328668
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.47	5.47	0.36	5.82	10.12	0.6
0.4-0.8km at 700m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	74.665	68.4575	52.0475	48.16333333	36.16666667	43.7375	60.4875
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.090676697	1.434554974	1.550245692	2.064470046	1.707116319	1.23438727
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.45	5.37	0.35	5.89	9.91	0.59
0.8-1.2km at 1100	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	75.0625	67.915	53.9225	49.14333333	36.17666667	43.195	60.5525
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.105241846	1.392044137	1.527419792	2.074887128	1.737759	1.23962677
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.47	5.21	0.35	5.91	10.09	0.6

3.97%	At 15+600						
0-0.4km, at 380	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	88.03	71.2075	54.9725	62.6375	-	44.55	55.565
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.236246182	1.601346128	1.405388146	-	1.975982043	1.584270674
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.64	5.99	0.32	-	11.47	0.76
0.4-0.8km at 700m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	83.74	66.0275	53.4475	59.64	-	44.21666667	54.285
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.268259437	1.566771131	1.404091214	-	1.893856012	1.542599245
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.68	5.86	0.32	-	10.99	0.74
0.8-1.2km, at 1100	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	81.1575	63.5525	51.84	57.64	-	44.2975	55.1175
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.277015066	1.565538194	1.408006593	-	1.832101134	1.472445231
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.69	5.85	0.32	-	10.63	0.71
>1.2km at 1800	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	78.3	57.2775	52.595	63.4475	-	41.3375	54.285
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.367028938	1.488734671	1.234091178	-	1.894163895	1.4423874
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.81	5.57	0.28	-	10.99	0.69

-0.80%	at 21+900						
0-0.4km, at 380m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.3975	63.34	49.2675	54.5975	38.9925	44.04	53.7425
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.032483423	1.327396357	1.197811255	1.677181509	1.484956857	1.21686747
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.37	4.96	0.27	4.78	8.62	0.59
0.4-0.8km, At 700m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.11	61.895	50.18	58.575	39.6175	43.19	53.365
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.051942806	1.297528896	1.111566368	1.64346564	1.50752489	1.220088073
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.4	4.85	0.25	4.69	8.75	0.59
0.8-1.2km, at 1100m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.1925	61.74	51.285	61.5825	39.105	43.405	53.405
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.055919987	1.271180657	1.05862055	1.66711418	1.5019583	1.220719034
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.4	4.75	0.24	4.75	8.72	0.59

7.50%	at 2+500						
0-0.4km, at 200m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	77.02583333	56.8625	48.81166667	61.836	31.37857143	-	58.22666667
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.35459808	1.578020965	1.245647088	2.454727218	-	1.322861804
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.8	5.9	0.28	7	-	0.64
0.4-0.8km, at 575m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj

Average Speed	71.965	49.14916667	48.265	57.095	30.25	-	57.90090909
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.464216077	1.491039055	1.260443121	2.379008264	-	1.242899311
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.94	5.58	0.29	6.78	-	0.6
0.8-1.2km, at 1100	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	71.05333333	47.43	48.78416667	60.13	29.545	-	58.42416667
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.498067327	1.45648349	1.181661955	2.40491905	-	1.216163403
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.99	5.45	0.27	6.86	-	0.59
>1.2km, at 2km	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	70.675	47.7525	50.20666667	59.6275	31.248	-	59.815
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.480027224	1.407681583	1.185275251	2.261744752	-	1.181559809
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.96	5.26	0.27	6.45	-	0.57

4.40%	25+200						
0-0.4km at 380	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	63.9925	57.0125	49.86	53.28	43.19	44.695	51.01
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.122429292	1.283443642	1.201060435	1.481650845	1.431759705	1.25450892
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.49	4.8	0.27	4.22	8.31	0.6
0.4-0.8km at 700m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	63.16	55.9575	48.9475	55.975	42.57	44.595	49.115

Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.128713756	1.290362123	1.128360875	1.483673949	1.416302276	1.285961519
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.5	4.83	0.26	4.23	8.22	0.62
0.8-1.2km at 1100m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	63.2075	55.2125	48.995	54.595	42.46	42.88	49.21
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.144804166	1.29008062	1.157752541	1.488636364	1.474055504	1.284444219
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.52	4.82	0.26	4.24	8.55	0.62
>1.2km at 1420m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	62.5525	55.2825	49.49	51.67	39.1725	43.66	47.94
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.131506354	1.263942211	1.210615444	1.596847278	1.432718736	1.304808093
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.5	4.73	0.28	4.55	8.31	0.63

1.85%	at 7+160						
0-0.4km at 380m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	72.58	66.5125	52.28	-	45.90666667	44.39	58.17
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.091223454	1.388293803	-	1.581033982	1.63505294	1.247722194
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.45	5.19	-	4.51	9.49	0.6
0.4-0.8km at 700m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	71.25916667	63.65727273	50.66666667	-	41.57166667	41.775	58.662

Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.119419096	1.406430921	-	1.714128212	1.705784959	1.214741514
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.49	5.26	-	4.89	9.9	0.59
0.8-1.2km at 1100m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	72.14416667	68.09818182	52.39333333	-	44.955	41.455	55.96727273
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.059413992	1.376972261	-	1.604808512	1.740300728	1.289042027
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.41	5.15	-	4.57	10.1	0.62
>1.2km at 1460	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	72.9275	64.91416667	52.42	-	44.27	39.98	53.64
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.123445062	1.391215185	-	1.647334538	1.82409955	1.35957308
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.49	5.2	-	4.7	10.59	0.65

1.46%	19+500						
0-0.4km at 380m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	65.97583333	55.11363636	49.8425	51.94571429	43.22	18.21857143	42.23818182
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.197087285	1.323686278	1.270091946	1.526511646	3.621350532	1.561995107
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.59	4.95	0.29	4.35	21.02	0.75
0.4-0.8km	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	66.0975	52.47909091	49.72083333	53.65428571	41.73583333	19.22714286	41.50545455

Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.25950162	1.329372329	1.231914639	1.58371104	3.437718255	1.592501533
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.67	4.97	0.28	4.51	19.95	0.77
0.8-1.2km at 1100m	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	66.25083333	51.27666667	48.26416667	53.24333333	42.9425	18.1875	40.80090909
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.292026913	1.372671236	1.244302886	1.542780074	3.642657503	1.623758755
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.71	5.13	0.28	4.4	21.14	0.78
>1.2km at 1460	Car	Light Truck	Bus	Motor Bike	Medium Truck	Articulated	Bajaj
Average Speed	66.45333333	53.92636364	48.18166667	54.09714286	42.68083333	18.9575	41.62
Average Vehicle Dimension	7.535	10	28.18	1.72	21.48	43.73	3.63
Vc/Vi	1	1.23229769	1.379224463	1.22840745	1.556983033	3.505384852	1.596668268
Ac/Ai	1	0.7535	0.267388219	4.380813953	0.350791434	0.17230734	2.075757576
PCE From Simulation	1	1.64	5.16	0.28	4.44	20.34	0.77