ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GRADUATE STUDIES

PASSENGER CAR EQUIVALENTS FOR BASIC FREEWAY SEGMENTS ON ADDIS ABABA – ADAMA EXPRESSWAY

By

Girum Tamene

Thesis submitted to school of civil and environmental engineering of Addis Ababa institute of technology in partial fulfilment of the requirements for the degree of

Master of Science

In

Civil Engineering

(Road and Transport Engineering)

Advisor

Dr. Bikila Teklu

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Addis Ababa, Ethiopia

Addis Ababa University

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Approved by Board of Examiners:

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Declaration

I certify that research work titled *"Passenger Car Equivalents for Basic Freeway Segments on Addis Ababa – Adama Expressway"* is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged / referred.

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Abstract

In freeway traffic flow contains different types of vehicles, due to the variation of vehicles in the traffic flow the speed of passenger cars influenced by heavy vehicles, for the reason that heavy vehicles uses more driving area of the road and limited performance. Hence according to local conditions developing Passenger Car Equivalents (PCE) for trucks and buses on upgrade and down grade is an essential parameter. So the major objective of this research is to evaluate Passenger Car Equivalents (PCE) for trucks and buses for basic freeway segments on Addis Ababa – Adama Expressway and compared with that of Highway Capacity Manual 2010 provided.

The data was collected from the field by using videotaping on Addis Ababa – Adama expressway in the selected sites on the basic freeway segments at every collection site for the percent grade with the corresponding grade length. And the development of Passenger Car Equivalent was carried out by transcribing the recorded video in to tabular form with proportion of trucks and buses, base flow rate and mixed flow rate and also analyzed by using Equal Flow Density method.

In this study the proportion of trucks and buses considered from 10% up to 50%, the Passenger Car Equivalent increases as the proportion of trucks and buses decreases. The major variation observed in lower trucks and buses proportion non-linearly because the interaction between trucks and buses with passenger cars increases. Moreover for trucks and buses proportions from 10 % up to 50 %, the value of PCE varies in between 1.4 up to 7.8 for upgrade up to 5 % which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0. For trucks and buses proportions of 10 %, the value of PCE varies with the length of grade in between 5.6 up to 7.8 for 5 % upgrade which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0.

The study concludes that while analyzing by using the executed Passenger Car Equivalents shows a better assumption than Passenger Car Equivalents on HCM 2010. So the executed Passenger car Equivalents for the basic freeway segment on Addis Ababa – Adama Expressway provides a realistic result while analyzing the traffic flow.

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Abbreviations

d: Distance Traverse

D: Density of the Traffic Stream

E_R: Passenger Car Equivalents for Recreational Vehicles

ERA: Ethiopian Roads Authority

ESA: Equivalent Standard Axels

E_T: Passenger Car Equivalents for Trucks and Buses

FFS: Free Flow Speed

f_{HV}: Heavy Vehicles Factor

f_p: Non-familiar users Adjustment Factor

GPS: Global Positioning System

HCM: Highway Capacity Manual

LOS: Level of Service

n: Number of Vehicles

N: Number of Lanes

PC: Passenger Car

PCE: Passenger Car Equivalents

PHF: Peak-hour Factor

P_R: Proportion of Recreational Vehicles

P_T: Proportion of Trucks and Buses

q_B: Base Flow Rate

q_M: Mixed Flow Rate

S: Speed

t: Time for a vehicle to traverse a section

V: Hourly Volume

Veh: Vehicle

V_{m15}: Maximum 15-minute Volume within the hours

v_p: Demand Flow Rate

Chapter 1. Introduction

1.1 Background

In traffic facilities there are two types of flow uninterrupted and interrupted flow. Uninterrupted flow exists when traffic stream does not have external interruption such flow exist in freeways but doesn't describe the quality of operation.

Toll roads are similar to a freeway according to HCM 2010 so the Addis Ababa – Adama Expressway considered as a freeway and the study was done on this route in a basic freeway segment. To realize that in basic freeway segments there are two crucial necessities, in what extent the traffic service can provide and under what maneuvering situations. Hence these necessities lead to operational analysis, service flow rate and service volume analysis and design analysis.

In basic freeway segments the traffic flow contains different types of vehicles due to this the speed of passenger cars influenced by heavy vehicles for the reason that they use more driving area of the road and limited performance while accelerating, decelerating and ability to keep speed on grades. The effect of a grade depends on both the length and slope of the grade. So, on steep upgrade the effect greatly noticeable and when steep enough in down grade travelling in a lower gear, Due to this trucks and buses form gaps in traffic flow.

To be consistent while analyzing the effect of trucks and buses converted in to corresponding number of passenger car by using Passenger Car Equivalent.
"Passenger Car Equivalent as defined in HCM 2010, the number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic and control conditions''.

The Passenger Car Equivalents for truck and buses was computed by using the Equal Flow Density methodology and a new Passenger Car Equivalent was proposed for Addis Ababa - Adama Expressway.

1.2 Objectives

1.2.1 General Objective

The general objective of this research is to evaluate Passenger Car Equivalents for trucks and buses for basic freeway segments on Addis Ababa – Adama Expressway.

1.2.2 Specific Objective

- ✓ To compare and contrast the new Passenger Car Equivalent (PCE) with that of HCM 2010 provided.
- ✓ The Passenger Car Equivalent (PCE) proposed by this research is that valuable in improving the accuracy of the traffic stream analysis.
- ✓ To verify that the Passenger Car Equivalent (PCE) values increases non-linearly with the decrease in percentage of trucks and buses.
- ✓ To verify that the Passenger Car Equivalent (PCE) values increases non-linearly with the increase in the length of grade.
- ✓ To verify that the Passenger Car Equivalent (PCE) values increases non-linearly with the increase in the percent grade.
- ✓ Evaluating the operational analysis for the Expressway based on the executed Passenger Car Equivalent (PCE) and HCM 2010.
- ✓ To suggest new Passenger Car Equivalents for trucks and buses for basic freeway segments according to the local conditions which is the performance of the vehicles, the geometrical design, the traffic flow characteristics and behavior of drivers.

1.3. Statement of the problem

In Ethiopia the Passenger Car Equivalents for trucks and buses taken from HCM 2010 while doing the operational analysis, the service flow rate and service volume analysis, and the design analysis for the traffic flow. But HCM 2010 warns the international users may require adjustment to local situations and understanding differences. So, developing Passenger Car Equivalents for trucks and buses in upgrade and down grade is an essential parameter according to local conditions.

From this study, developing of Passenger Car Equivalents should be helpful for Ethiopian traffic engineers who plan, design, operate and maintain freeways corresponding to the local traffic stream flow, also specifically benefits to improve traffic circulation and enhance safety.

The reason to conduct this research is that from different studies every country has different traffic flow characteristics and vehicles performance due to this different study have got different Passenger Car Equivalent values. Thus developing these values is an essential for the country to design, plan, operate and maintain freeways corresponding to the local traffic stream flow. And also needs improvements to the accuracy of analysis and design of freeways.

A new construction of freeway may be need in the country in the future so developing Passenger Car Equivalent according to the local traffic stream flow is the basic one. Also a proper selection of Passenger Car Equivalent values is an essential for analysis.

For the future, more researches need on such topics due to the difference on the traffic flow and performance of vehicles from the regions of one country to the other or from one country to the other country.

1.4. Limitations of the Study

In this study the results depend on set of limitations and criterion in to account on the following:

- ✓ Due to financial constraint the video recording was done only for consecutive three hours.
- ✓ Trucks and Buses include smaller bus up to truck trailer as a one group while evaluating PCE values.
- ✓ The data collected at station D which is found in between Mojo and Adama towns, the traffic flow was lower than the other segments in the expressway so the evaluated PCE values are lower than the other segments.

1.5. Organization of the Thesis

This thesis consists of five chapters and an Appendix. Chapter 1 is an introduction, which includes the background, objectives, statement of the problem, limitations of the study and organization of the thesis. Chapter 2 is the literature review, which discuss the theoretical framework for the study. Chapter 3 presents the methodology and research design in detail. Chapter 4 focuses on the discussion and results of the study. Chapter 5 forwards conclusions and recommendations of the research. Appendix A shows profile data for Addis Ababa – Adama Expressway. Appendix B displays the data collection sheet. Appendix C illustrates data collected for free flow speed. Appendix D demonstrates the summarized executed PCEs values and the transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway. Appendix E shows sample calculation to determine PCE. Appendix F exhibits example problem on operational analysis. Appendix G displays the sample location where the data was taken.

Chapter 2. Literature review

2.1 Truck equivalencies

Trucks and buses equivalencies stated throughout the development of Highway Capacity Manual (HCM) for two lane highways, multilane highways and freeways.

With a joint venture between the Highway Research Board's Committee on Highway Capacity and the Bureau of Public Roads the first Highway Capacity Manual (HCM) was published in 1950. According to the edition cited by Marlina (2012) trucks on two-lane highways on level terrain have the same effect as two passenger cars (PC).

With the Highway Research Board and authored by the Committee on Highway Capacity the second Highway Capacity manual edition was published in 1965. According to the edition cited by Marlina (2012) Passenger Car Equivalent (PCE) was introduced and defined as "the number of passenger cars displaced in the traffic flow by a truck or bus, under the prevailing roadway and traffic conditions".

In Highway Capacity Manual 2010 Passenger Car Equivalent defined as "the number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions".

2.2 Freeway and Basic Freeway Segment

According to Highway Capacity Manual 2010, "Freeway defined as separated highways with full control of access and two or more lanes in each direction dedicated to the exclusive use of traffic". Freeway is a set of continuously connected basic freeway, weaving, merge, and diverge segments.

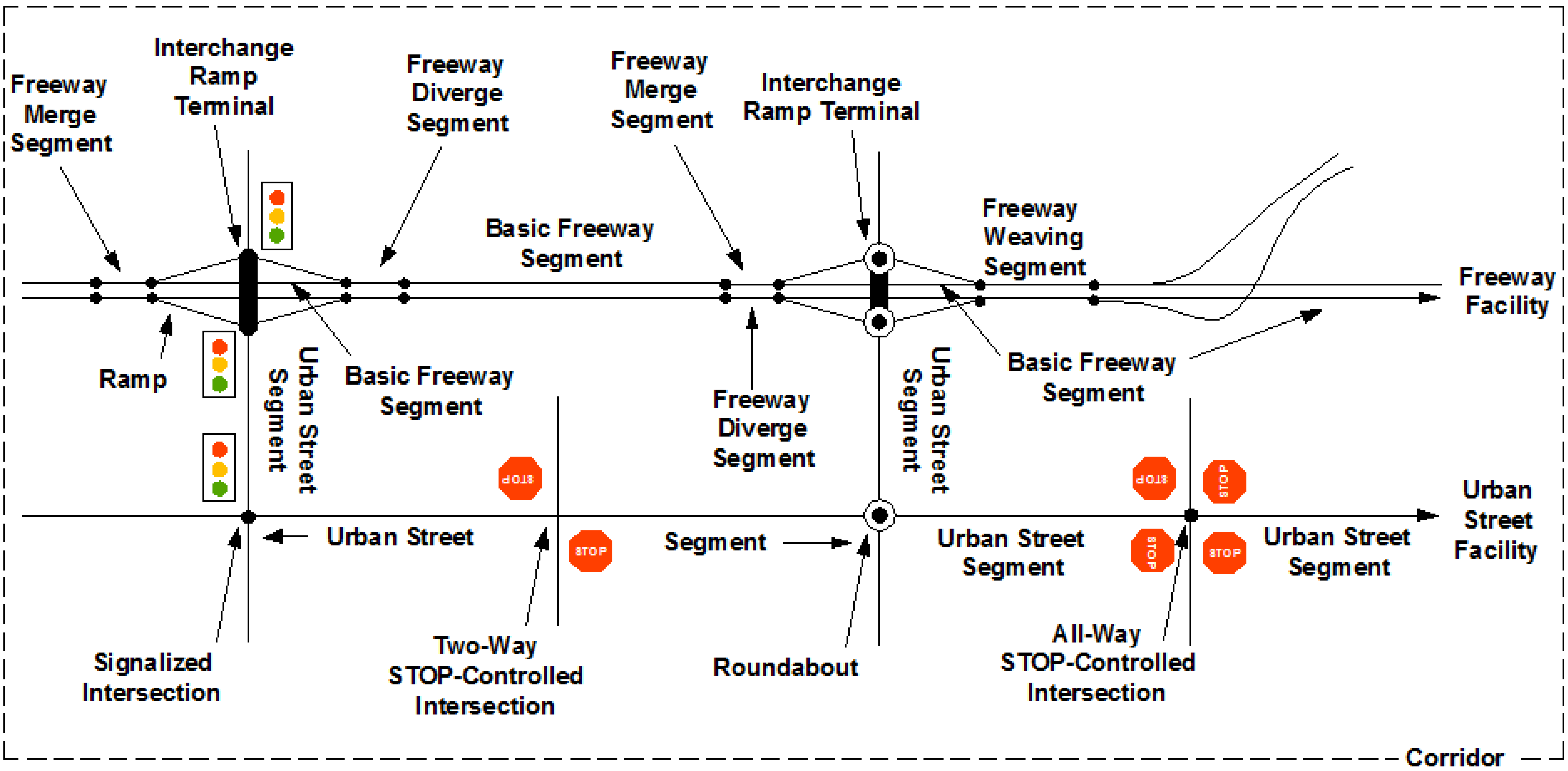


Figure 2.1: Illustrative Roadway System Elements (Points, Segments, Facilities, and Corridors)

(HCM 2010:p.2-4)

Basic freeway segments as defined in Highway Capacity Manual 2010 “those freeway segments that are outside the influence of merging, diverging, or weaving maneuvers, that lane changing activity is not significantly influenced by the presence of ramps and weaving segment”.

A segment is the length of roadway between two points. Traffic volumes and physical characteristics generally remain the same over the length of a segment, although small variations may occur (e.g., changes in traffic volumes on a segment resulting from a low-volume driveway).

2.3 Types of freeway analysis

For basic freeway section there are three types of analysis that can carry out, those are Operational analysis, Service flow rate and service volume analysis, and Design analysis.

2.3.1 Operational Analysis

In Operational Analysis, all traffic, roadway, and control conditions are defined for an existing or projected highway section, and the expected level of service and operating parameters are determined.

The basic approach is to convert the existing or forecast demand volumes to an equivalent flow rate under ideal conditions (Roess, 2004):

$$v_p = \frac{V}{PHF * N * f_{HV} * f_p} \qquad [2.1]$$

Where:

v_p = demand flow rate under equivalent ideal conditions, pc/h/ln

PHF = peak-hour factor

N = number of lanes (in one direction) on the facility

f_{HV} = adjustment factor for presence of heavy vehicles

f_p = adjustment factor for presence of occasional or non-familiar users of a facility

2.3.2 Service Flow Rate and Service Volume Analysis

In Service Flow Rate and Service Volume Analysis determine the service flow rates and service volumes for the various levels of service under prevailing conditions. For a speedy determination of expected level of service various demand levels may then be compared to these estimates.
The service flow rate for a given level of service is computed as (Roess, 2004):

$$SF_i = MSF_i * N * f_{HV} * f_p \qquad [2.2]$$

Where:
SF_i = service flow rate for level of service "i," veh/h
MSF_i = maximum service flow rate for level of service "i," pc/h/ln
N = number of lanes (in one direction) on the facility
f_{HV} = adjustment factor for presence of heavy vehicles
f_p = adjustment factor for presence of occasional or non-familiar users of a facility

Service flow rates are stated in terms of peak flows within the peak hour, usually for a 15-minute analysis period. By using equation 2.3 the peak-hour factor is suitable to convert service flow rates to service volumes over the full peak hour (Roess, 2004):

$$SV_i = SF_i * N * PHF \qquad [2.3]$$

Where:
SV_i = service volume over a full peak hour for level of service "i"
SF_i = service flow rate for level of service "i," veh/h
PHF = peak-hour factor

2.3.3 Design Analysis

In design analysis, to determine the number of lanes needed to provide for a specified level of service an existing or forecast demand volume is used.
The number of lanes may be computed as (Roess, 2004):

$$N_i = \frac{DDHV}{PHF * MSF_i * f_{HV} * f_p} \qquad [2.4]$$

Where:

N_i = number of lanes (in one direction) required to provide level of service "i''

DDHV = directional design hour volume, veh/h

MSF_i = maximum service flow rate for level of service "i," pc/h/ln

f_{HV} = adjustment factor for presence of heavy vehicles

f_p = adjustment factor for presence of occasional or non-familiar users of a facility

Design analysis for freeways becomes an iterative process. For freeways the free-flow speed is dependent upon the number of lanes provided. Thus, a number must be assumed, then computed, continuing to iterate until the assumed and computed values agree.

Afterwards the demand volume or flow rate can be compared to the results for a simpler determination of the required number of lanes.

2.4 Determining the Heavy-Vehicle Factor

The most important adjustment to demand volume is the Heavy Vehicle Factor, which adjusts for the presence of heavy vehicles in the traffic stream. According to HCM 2010, "Heavy vehicle defined as a vehicle with more than four wheels touching the pavement during normal operation".

For this research trucks and buses are the two types of heavy vehicle and both have similar characteristics (due to their size and performance) then placed in the same categories for analysis purpose.

The heavy vehicle adjustment factor is based upon the concept of Passenger Car Equivalents.

The number of passenger car equivalents in the traffic stream may be expressed as (Roess, 2004):

$$V_{pce} = (V_{vph} * P_T * E_T) + (V_{vph} * P_R * E_R) + (V_{vph} * (1 - P_T - P_R)) \qquad [2.5]$$

Where:

P_T = proportion of trucks and buses in the traffic steam (expressed as a decimal fraction)

P_R = proportion of RVs in the traffic stream (expressed as a decimal fraction)

E_T = passenger car equivalent for trucks and buses

E_R = passenger car equivalent for RVs

The adjustment factor for heavy vehicles stated as (Roess, 2004):

$$f_{HV} = \frac{V_{vph}}{V_{pce}}$$

$$= \frac{V_{vph}}{\left(V_{vph} * P_T * E_T\right) + \left(V_{vph} * P_R * E_R\right) + \left(V_{vph} * (1 - P_T - P_R)\right)}$$

Simplified as:

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad [2.6]$$

Where:

f_{HV} = heavy vehicle factor

V_{vph} = flow rate, veh/h

V_{pce} = flow rate, pce/h

2.5 Determination of Passenger Car Equivalent

Passenger Car Equivalent defined in HCM 2010 as "the number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic and control conditions".

Any freeway grade between 2% and 3% and longer than 0.8 km or 3% or greater and longer than 0.4 km should be considered a separate segment. The analysis of such segments must consider the upgrade conditions and the downgrade conditions separately (HCM 2010:p.11-15). Hence both heavy-vehicle operation and the characteristics of the entire traffic stream may have substantially impacted due to a long grade.

To commence the determination of Passenger Car Equivalent for specific grade first establish a set of base condition for basic freeway segments. The base conditions of a basic freeway segment are good weather, good visibility, and no incidents or accidents. For this thesis, these base conditions exist.

To determine Passenger Car Equivalents there are different types of methods, from those:

2.5.1 PCEs by Flow rates and Density method

Whether the road is congested or not measuring the traffic flow is critical on the roadway. Traffic flow rate is the term used to indicate the equivalent hourly rate of vehicles passing a point per unit of time

John and Glauz (1976) as cited by Marlina (2012) computed based on mixed vehicle flow, percentage of grade and truck volume to capacity ratio:

$$E_T = \frac{q_B - q_M\ (1 - P_T)}{q_M \text{ X } P_T} \qquad [2.7]$$

Where

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

q_M = mixed flow rate

P_T = truck proportion in the mixed traffic flow

E_T = truck PCE

To relate PCE to the flow of a passenger car only traffic stream and mixed vehicle traffic stream Huber (1982) as cited by Marlina (2012) derived equation (2.7) in a various functional form. Huber used the assumption of equal average travel time as the measure of LOS.

$$E_T = \frac{1}{P_T}\left(\frac{q_B}{q_M} - 1\right) + 1 \qquad [2.8]$$

Where

P_T = the proportion of trucks in the mixed traffic flow

q_B = the base flow rate (passenger cars only)

q_M = the mixed flow rate

To compute the PCE of a single truck in a mixed traffic stream, which includes multiple truck types, Sumner et al (1984) as cited by Marlina (2012) expanded the relationship expressed by Huber. The relationship described by Sumner et al is formulated as:

$$E_T = \frac{1}{\nabla P}\left(\frac{q_B}{q_S} - \frac{q_B}{q_M}\right) + 1 \qquad [2.9]$$

Where

∇P = the proportion of subject vehicles that is added to the mixed flow and subtracted from the passenger car proportion

q_B = the base flow rate (passenger cars only)

q_M = the mixed flow rate

q_S = the flow rate including the added subject vehicles

E_T = truck PCE

The PCE's formula proposed by Demarchi and Setti (2003) - to avoid the possible error for mixed heavy vehicles in the traffic stream, including interaction between multiple trucks types. The relationship formulated as:

$$E_T = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1 \quad [2.10]$$

Where:

E_T = Passenger equivalent of trucks

P_i = Proportion of trucks of type i out of all trucks n in the mixed traffic flow

q_B = base flow rate (passenger cars only)

q_M = mixed flow rate (passenger cars + trucks)

In HCM 2010 the Passenger Car Equivalent values for basic freeway segment based on the percentages of trucks, buses, and RVs in the traffic stream as well as type of terrain (grade profile and its length) and the analysis based on flow rates.

2.5.2 PCEs by Headways method

Headway defined as "the time between two successive vehicles as they pass a point on the roadway, measured from the same common feature of both vehicles (for example, the front axle or the front bumper" (HCM 2010).

Headways have been used for the most popular methods to calculate truck equivalencies by the effects of heavy vehicles in the traffic stream because of they occupy more space. Researchers have used headway as the basis of estimation.

Werner and Morrall (1976) as cited by Ingle (2004) suggested that using head way method is appropriate to determining PCE when the roadway is sufficiently congested on level terrain:

$$E_T = \frac{\left(\frac{H_M}{H_B} - P_C\right)}{P_T} \qquad [2.11]$$

Where

H_M = average headway for all vehicles

H_B = average headway for passenger car

P_T = truck proportion

P_C = passenger car proportion

E_T = truck PCE

Seguin, et.al (1982) as cited by Shalini and Kumar (2014) by using the spatial headway methodology PCE formulated as the ratio of average headway for vehicle types: average truck headway divided by the average headway for passenger cars:

$$PCE_{ij} = \frac{H_{ij}}{H_{PCj}} \qquad [2.12]$$

Where

PCE_{ij} = the PCE of vehicle Type i under Conditions j

H_{ij} = average headway for vehicle Type i

H_{PCj} = the average headway for passenger car for Conditions j.

Based on headway type, lane width, and traffic volume Cunagin and Chang (1982) as cited by Shalini and Kumar (2014) determined the effect of the presence of heavy trucks on freeway traffic streams using time headway. And they conclude that the presence of trucks in the traffic stream is accompanied by an increase in the mean headway. The lagging headway is measured from the rear bumper of the lead vehicle to the rear bumper of the following vehicle.

$$E_T = \frac{H_{ij}}{H_B} \qquad [2.13]$$

Where

H_{ij} = the mean lagging headway of vehicle type i under conditions j

H_B = the mean lagging headway of passenger cars.

E_T = truck PCE

On the findings of Cunagin and Chang contrary, the lagging headway for trucks following trucks was found to be significantly less than the lagging headway for cars following trucks. Hence Krammes and Crowley (1986) as cited by Ingle (2004) suggest that:

$$E_T = [(1 - P_T).H_{TP} + p.H_{TT}]/H_P \qquad [2.14]$$

Where

P_T = the proportion of trucks

H_{TP} = the lagging headway of trucks following passenger cars

H_{TT} = the lagging headway of trucks following trucks

H_P = the lagging headway of cars following either vehicle type

E_T = truck PCE

2.5.3 PCEs Based on Queue Discharge Flow

A queue occurs when the vehicles move a sequence of start and stops, and creates a large amount of vehicles over a period of time on upstream of a bottleneck. It occurs when the availability of capacity is not capable of performing the demand of vehicles.

Al-Kaisy et al. (2002) as cited by Marlina (2012) enumerate the calculation of PCE by using queue discharge flow based on the statement that if the traffic stream is uniform and consists of passenger cars only queue discharge flow, capacity observation can be expected to show minimal variation. They obtain the effect of heavy vehicles on a freeway is greater during maneuvering in oversaturated conditions.

2.5.4 PCEs by speed method

Van Aerde and Yagar (1984) as cited by Ingle (2004) developed a methodology to estimate PCE based on the relative rates of speed for each type of vehicle traveling in the main direction and for all vehicles combined traveling in the opposing direction. They found that PCE decreases for higher speed percentiles. The speed analysis using the linear regression model structure is:

Percentile speed = free speed + C_1 (number of passenger cars)

+ C_2 (number of trucks)

+ C_3 (number of RVs)

+ C_4 (number of other vehicles)

+ C_5 (number of opposing vehicles) [2.15]

Where:

C1 to C5 = the coefficients of speed reductions for each vehicle type

Using the speed reduction coefficients, the PCE for a vehicle type n is calculated as:

$$E_n = \frac{C_n}{C_1} \qquad [2.16]$$

Where:

E_n = truck PCE

C_n = speed reduction coefficient for vehicle type n

C_1 = speed reduction coefficient for passenger cars

2.5.5 PCEs based on Delays

By using Walker spatial-headway and equivalent-delay methods the PCE values are computed. A basic approach in the Walker method is that at low traffic volumes faster vehicles will not likely be obstructing in overtaking other vehicles. However at higher traffic volumes, for instance challenging to traverse a section, slower overtaking vehicles will obstruct faster vehicles. As a consequence queue formation in the overtaking lane.

With that principle, PCE values calculated using a linear combination of the Walker and equivalent-delay in each intermediate volume level yields:

$$E_T = \frac{(OT_i/VOL_i)\,[(1/SP_M) - (1/SP_B)]}{(OT_{LPC}/VOL_{LPC})[(1/SP_{PC}) - (1/SP_B)]} \qquad [2.17]$$

Where

OT_i = the number of overtakings of vehicle type i by passenger cars

VOL_i = the volume of vehicle type i

OT_{LPC} = the number of over takings of lower performance passenger cars by passenger cars

VOL_{LPC} = the volume of lower performance passenger cars

SP_M = the mean speed of the mixed traffic stream

SP_B = the mean speed of the base traffic stream with only high performance passenger cars

SP_{PC} = the mean speed of the traffic stream with only passenger cars

E_T = truck PCE

A Passenger Car Equivalent introduced by Craus et al. (1980) as cited by Shalini and Kumar (2014) the ratio of delay time caused by one truck to the delay time caused by one passenger car. This technique is done by considering the opposite-lane traffic. The actual disturbance and delay caused by trucks to other traffic according to the following equation:

$$E = \frac{d_{kt}}{d_{kp}} \qquad [2.18]$$

Where

E = truck PCE

d_{kt} = average delay time caused by one truck

d_{kp} = average delay time caused by one passenger car

Passenger Car Equivalent introduced by Cunagin and Messer (1983) as cited by Shalini and Kumar (2014) based on speed distribution, traffic volumes, and vehicle types. To determine the PCE their technique were using the ratio of delay experienced by a passenger car due to non-passenger vehicles to the delay experienced by a passenger car due to other passenger cars:

$$E_T = \frac{D_{ij} - D_{base}}{D_{base}} \qquad [2.19]$$

Where

E_T = PCE of vehicle Type i under Conditions j

D_{ij} = delay to passenger cars due to vehicle Type i under Conditions j

D_{base} = delay to standard passenger cars due to slower passenger cars

2.5.6 PCEs based on V/C Ratio

Fan (1990) as cited by Ingle (2004) considering PCE in Singapore expressways by using volume-to-capacity (V/C) ratio on operate at LOS E. The aim of study is that computing PCE above 0.67 by using V/C ratio and cited that no need of computing PCEs at uncongested flow conditions.

A multiple linear regression equation whereby the v/c ratio was related to the PCE multiplied by the observed flow of each vehicle type and this relationship is that the purposeful form of Fan.

2.5.7 PCEs Based on Vehicle-Hours

Sumner et al. (1984) as cited by Marlina (2012) find out to compute PCE values between consecutive signalized intersections on urban arterial roads using microscopic simulation, NETSIM. When large vehicles are presented to the traffic stream the PCE values derived from the vehicle-hours of road utilization. The analysis established that PCE is lower for better levels of service.

2.6 Working definition for the study

The equivalency values represent the number of passenger cars that would use the same amount of freeway capacity as one truck or bus under prevailing conditions. The freeway capacity that was the maximum sustainable flow rate at which vehicles expected to reasonably traverse a point or uniform segment of a lane or roadway during a specified time period under a given roadway, geometric, traffic, environmental and control conditions. So it is a time equivalence working method.

2.7 Truck and bus equivalencies

2.7.1 Trucks and bus equivalencies in HCM 2010

According to HCM 2010 for Equivalents for specific upgrades the values of E_T for trucks and buses with the percent grade, length of grade and the proportion of heavy vehicles in the flow of traffic, as shown on Table 2.1

Table 2.1: PCEs for Trucks and Buses (E_T) on Specific Upgrades (HCM 2010)

(HCM 2010:p.11-16)

Upgrade (%)	**Length (km)**	**Proportion of Trucks and Buses**								
		2%	**4%**	**5%**	**6%**	**8%**	**10%**	**15%**	**20%**	**≥ 25%**
≤ 2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
> 2-3	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4 - 0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.8 - 1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 1.2 - 1.6	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.6 - 2.4	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 2.4	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3-4	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4 - 0.8	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.8 - 1.2	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 1.2 - 1.6	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.6 - 2.4	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 2.4	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4-5	0.0 - 0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4 - 0.8	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.8 - 1.2	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 1.2 - 1.6	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.6	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5-6	0.0 - 0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.4 - 0.5	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.5 - 0.8	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.8 - 1.2	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.2 - 1.6	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.6	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.0 - 0.4	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	1.0
	> 0.4 - 0.5	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.5 - 0.8	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.8 - 1.2	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 1.2 - 1.6	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.6	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Note: Interpolation for Percentage of trucks and buses is recommended to the nearest 0.1.

Table 2.2: PCEs for Trucks and Buses (E_T) on Specific Downgrades (HCM 2010)

(HCM 2010:p.11-17)

Downgrade (%)	Length of Grade (km)	Proportion of Trucks and Buses 5%	10%	15%	≥ 20%
< 4	All	1.5	1.5	1.5	1.5
4-5	≤ 6.4	1.5	1.5	1.5	1.5
	> 6.4	2.0	2.0	2.0	1.5
> 5-6	≤ 6.4	1.5	1.5	1.5	1.5
	> 6.4	5.5	4.0	4.0	3.0
> 6	≤ 6.4	1.5	1.5	1.5	1.5
	> 6.4	7.5	6.0	5.5	4.5

2.7.2 Trucks and bus equivalencies by Anthony Ingle

According to Anthony Ingle (July, 2004) by the study title *"Development of Passenger Car Equivalents for Basic Freeway Segments"* equivalents for specific upgrades the values of E_T for trucks and buses with the percent grade, length of grade and the proportion of heavy vehicles in the flow of traffic, as shown on Table 2.2.

Table 2.3: PCEs for Trucks and Buses (E_T) on Specific Upgrades (Anthony Ingle, 2004)

(Anthony Ingle (July, 2004):p.100)

Upgrade (%)	Length (km)	Proportion of Trucks and Buses												
		2%	4%	5%	6%	8%	10%	15%	20%	25%	30%	40%	50%	60%
	0.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
	0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
	1.21	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
1	1.61	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
	2.01	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
	2.41	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
	3.22	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0
	0.4	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.8	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	1.21	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2	1.61	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	2.01	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	2.41	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	3.22	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.4	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	0.8	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	1.21	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
3	1.61	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	2.01	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	2.41	3.5	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
	3.22	4.0	3.0	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
	0.4	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	0.8	3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5
	1.21	3.5	2.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
4	1.61	4.0	3.5	3.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0
	2.01	4.5	3.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0
	2.41	4.5	4.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0
	3.22	5.0	4.0	4.5	4.0	3.5	3.5	3.0	2.5	2.5	2.5	2.0	2.0	2.0
	0.4	3.5	2.5	2.5	2.5	2.0	2.5	2.0	2.0	2.0	2.0	2.0	2.0	1.5
	0.8	3.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.5	2.0	2.0	2.0
	1.21	5.5	4.0	3.5	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0
5	1.61	5.5	4.5	4.0	4.0	3.0	3.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0
	2.01	6.5	5.0	4.0	4.5	3.5	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.0
	2.41	6.5	5.0	5.0	4.5	3.5	3.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0
	3.22	7.5	5.0	5.5	5.0	4.5	4.0	3.5	3.0	3.0	3.0	2.5	2.5	2.0
	0.4	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	0.8	4.5	4.5	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.5	2.5	2.0
	1.21	7.5	5.5	5.5	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.5
6	1.61	7.0	6.0	6.0	6.0	5.0	4.5	3.5	3.5	3.0	3.0	3.0	2.5	2.5
	2.01	8.5	6.5	6.0	6.0	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5
	2.41	8.5	7.0	6.5	5.5	5.5	5.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5
	3.22	9.0	6.5	6.5	6.0	5.5	5.0	4.5	3.5	3.5	3.5	3.0	2.5	2.5
	0.4	5.0	5.0	4.5	4.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.0
	0.8	8.0	7.5	7.0	6.5	5.5	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5
	1.21	8.0	7.5	7.5	7.0	6.0	5.5	4.5	4.0	4.0	3.5	3.5	3.0	3.0
8	1.61	9.0	8.0	8.0	7.0	6.0	5.5	5.0	4.5	4.0	4.0	3.5	3.0	3.0
	2.01	9.5	8.0	8.0	7.0	6.0	6.0	5.0	4.5	4.0	4.0	3.5	3.0	3.0
	2.41	10.0	8.0	8.0	7.5	6.5	6.0	5.0	4.5	4.0	4.0	3.5	3.0	3.0
	3.22	10.5	9.5	8.5	7.5	6.5	6.0	5.0	4.5	4.5	4.0	3.5	3.0	3.0

2.7.3 Trucks and bus equivalencies by Al-Kaisy et al.

According to Al-Kaisy et al (Journal of Transportation Engineering © ASCE / July 2005) by the study title *"Developing Passenger Car Equivalency Factors for Heavy Vehicles during Congestion"* equivalents for specific upgrades the values of E_T for trucks and buses with the percent grade, length of grade and the proportion of heavy vehicles in the flow of traffic, as shown on Table 2.3.

Table 2.4: PCEs for Trucks and Buses (E_T) on Specific Upgrades (Al-Kaisy et al., 2005)

(Al-Kaisy et al. Journal of Transportation Engineering © ASCE / July 2005):p.520)

Upgrade (%)	**Length (km)**	**Proportion of Trucks and Buses**								
		2%	**4%**	**5%**	**6%**	**8%**	**10%**	**15%**	**20%**	**≥ 25%**
< 2	All	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.7
2	0.0 - 0.4	2.8	2.9	3.1	3.1	3.1	3.2	3.2	3.1	3.0
	> 0.4 - 0.8	2.9	3.0	3.1	3.2	3.1	3.3	3.2	3.1	2.9
	> 0.8 - 1.2	2.9	3.1	3.2	3.1	3.2	3.1	3.1	3.1	3.0
	> 1.2 - 1.6	2.9	3.1	3.1	3.0	3.2	3.3	3.1	3.0	2.9
	> 1.6 - 2.4	3.5	3.1	3.3	3.2	3.1	3.2	3.1	3.0	3.0
	> 2.4	4.2	3.5	3.3	3.4	3.3	3.3	3.2	3.0	2.9
3	0.0 - 0.4	3.0	3.5	3.3	3.3	3.3	3.4	3.2	3.2	3.0
	> 0.4 - 0.8	3.6	3.6	4.1	3.7	3.5	3.3	3.4	3.3	3.4
	> 0.8 - 1.2	3.0	3.3	4.0	3.4	3.7	3.6	3.4	3.1	3.3
	> 1.2 - 1.6	4.2	3.4	5.0	4.0	3.7	3.4	3.4	3.2	3.0
	> 1.6 - 2.4	4.6	3.5	4.7	4.7	3.7	3.5	3.4	3.2	3.1
	> 2.4	5.8	3.9	4.2	4.5	4.0	3.5	3.3	3.2	3.0
4	0.0 - 0.4	3.1	3.9	3.6	3.6	3.7	3.6	3.6	3.4	3.1
	> 0.4 - 0.8	4.8	4.1	4.2	3.8	4.1	4.0	3.9	3.5	3.3
	> 0.8 - 1.2	4.8	4.3	4.4	4.4	4.4	4.0	3.7	3.4	3.3
	> 1.2 - 1.6	5.5	4.1	4.3	4.0	4.8	3.7	3.7	3.5	3.3
	> 1.6	5.4	4.8	4.6	4.0	4.5	3.9	3.9	3.4	3.3
5	0.0 - 0.4	4.1	4.3	4.0	4.2	4.1	4.2	3.8	3.7	3.5
	> 0.4 - 0.5	4.7	4.6	4.5	4.9	4.7	4.7	4.3	3.8	3.6
	> 0.5 - 0.8	3.5	4.7	6.1	5.1	4.2	4.4	4.3	3.7	3.6
	> 0.8 - 1.2	5.9	6.3	5.9	5.7	5.4	4.7	4.3	3.8	3.5
	> 1.2 - 1.6	5.8	7.3	6.4	6.1	5.3	5.0	4.2	4.0	3.4
	> 1.6	6.8	7.7	7.0	6.7	5.4	5.4	4.2	3.7	3.5
6	0.0 - 0.4	4.7	4.9	5.6	4.9	5.4	5.0	4.5	4.5	3.8
	> 0.4 - 0.5	6.0	6.7	6.5	6.1	6.6	6.3	4.9	4.4	4.0
	> 0.5 - 0.8	7.3	6.9	6.9	7.2	6.5	6.0	5.1	4.5	4.3
	> 0.8 - 1.2	10.7	9.2	6.8	7.7	6.4	6.1	5.4	4.7	4.3
	> 1.2 - 1.6	10.3	9.4	8.6	8.3	7.9	7.7	5.7	4.7	4.1
	> 1.6	13.4	12.6	12.8	9.9	8.1	7.8	6.0	4.8	4.5

Figure 2.2 and Figure 2.3 shows the comparison between the PCE that was developed by HCM 2010, Anthony Ingle (July, 2004), and Al-Kaisy et al (Journal of Transportation Engineering © ASCE / July 2005) by trucks and buses proportion for > 0.8 – 1.2 km and > 1.6 km grade length on > 4 – 5 % upgrade respectively.

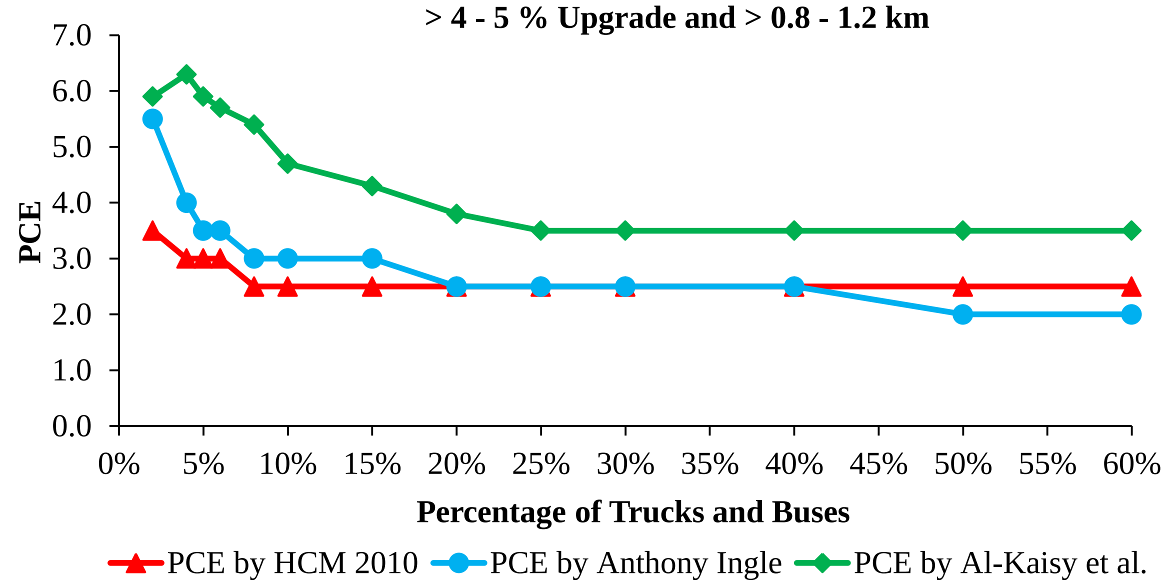


Figure 2.2: the comparison between the PCE that was developed by HCM 2010, Anthony Ingle, and Al-Kaisy et al. > 0.8 – 1.2 km grade length and > 4 – 5 % upgrade

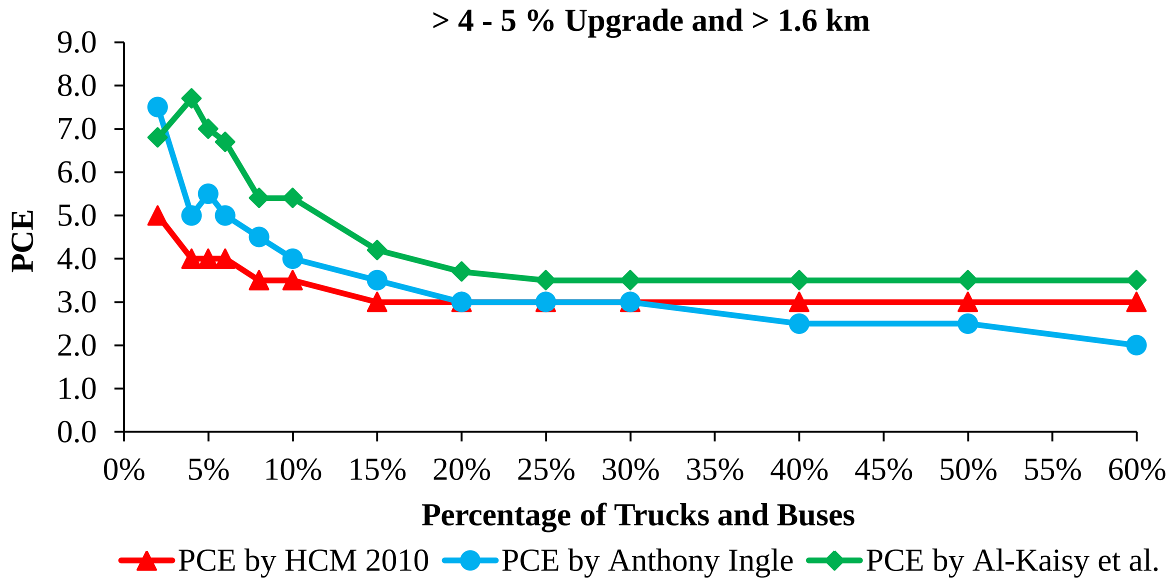


Figure 2.3: the comparison between the PCE that was developed by HCM 2010, Anthony Ingle, and Al-Kaisy et al. for > 1.6 km grade length and > 4 – 5 % upgrade

Figure 2.4 and Figure 2.5 shows the comparison between the PCE that was developed by HCM 2010, Anthony Ingle (July, 2004), and Al-Kaisy et al (Journal of Transportation Engineering © ASCE / July 2005) by grade length for > 4 – 5 % upgrade and 2 % and 10% trucks and buses respectively.

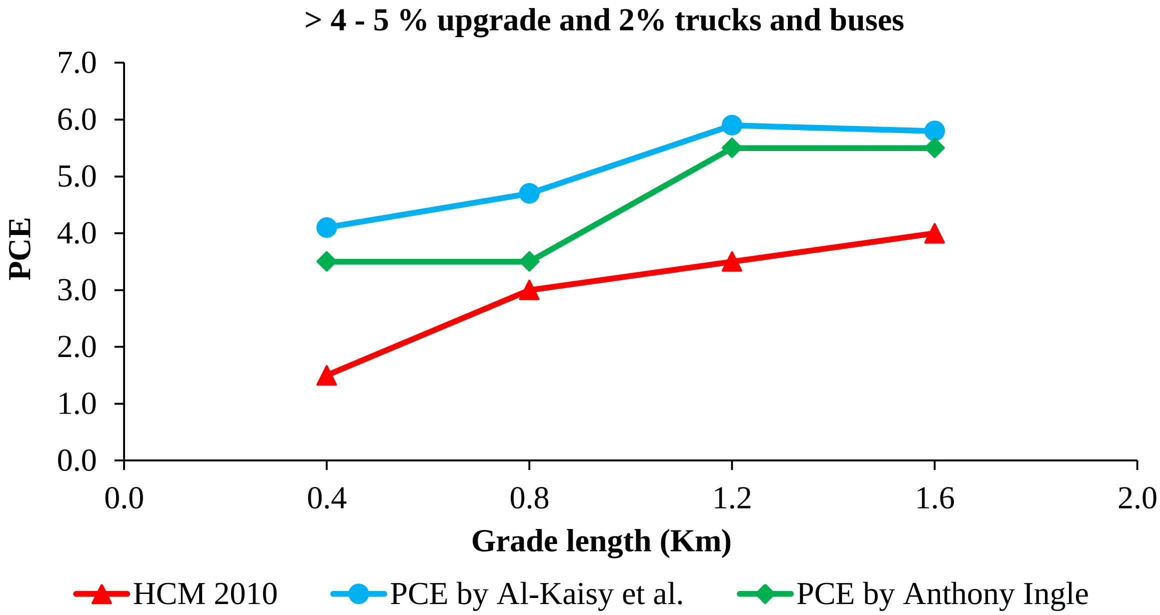


Figure 2.4: the comparison between the PCE that was developed by HCM 2010, Anthony Ingle, and Al-Kaisy et al. for > 4 – 5 % upgrade and 2 % trucks and buses

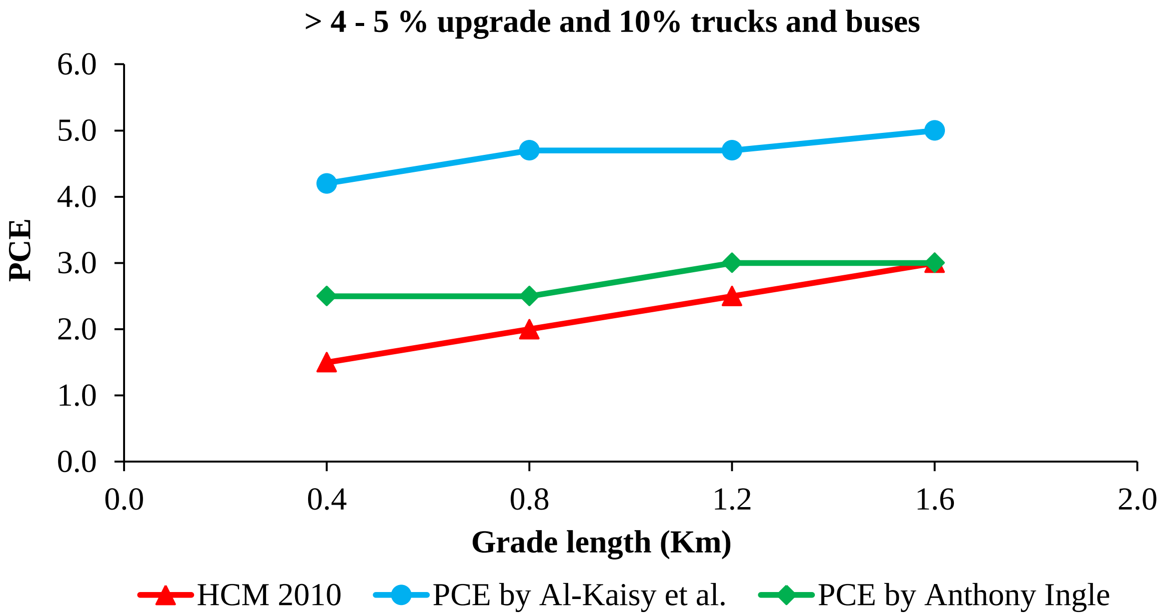


Figure 2.5: the comparison between the PCE that was developed by HCM 2010, Anthony Ingle, and Al-Kaisy et al. for > 4 – 5 % upgrade and 10 % trucks and buses

2.8 Vehicle classification

According to Ethiopian Roads Authority (ERA) divides vehicles into thirteen classes and shown in Table 2.3.

Table 2.5: Vehicle Classification

(ERA 2013:p.2-3)

ERA VEHICLE CLASSIFICATION					
CLASS	**TYPE**	**AXLES**	**DESCRIPTION**		
1	Car	2	Passenger cars and taxis		**Passenger Car**
2	Pick-up/4-wheel drive	2	Pick-up, minibus, Land Rovers, Land Cruisers		
3	Small Bus	2	≤ 27 seats		**Trucks and Buses**
4	Bus/coach	2	> 27 seats		
5	Small truck	2	≤ 3.5 tonnes		

Table 2.5 (Cont.): Vehicle Classification

(ERA 2013:p.2-3)

ERA VEHICLE CLASSIFICATION					
CLASS	**TYPE**	**AXLES**	**DESCRIPTION**		
6	Medium truck	2 or 3	3.5 - 7.5 tonnes		**Trucks and Buses**
7	Large 2-axled truck	2	> 7.5 tonnes		
8	3-axled truck	3	*		
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	*		
14	Unknown vehicle type				

* Not needed for definition

Chapter 3. Methodology

3.1 Overview

Among the methods that are listed in the literature review to calculate PCEs, the flow rates and density method was used for this research. The advantage of using flow rates and density method is that density is used in the HCM 2010 to define LOS. Density describes the proximity of vehicles to one another and reflects the freedom to maneuver within the traffic stream and density characterizes the quality of traffic operations for uninterrupted flow facilities.

In addition density is used to estimate service measures for basic freeway segment system and the common use of density measurements in the field makes it most practical for calculation of PCEs and also According to Marlina (2012) Equal Flow Density method is consistent and better.

In Highway Capacity Manual 2010 Passenger Car Equivalent defined as "the number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions". The PCE is also referred to as the number of passenger cars that would use the same amount of freeway capacity as a single truck or bus. In this sense of definition to equate PCE by using a passenger car only vehicle flow and a mixed vehicle flow.

Field observations should produce the most accurate representation of traffic flow in HCM 2010, so the collected data that was done by locally available equipment was compatible with the flow rates and density method. And also flow rate represents the equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval of less than 1 hour, usually 15 minutes as in HCM 2010.

3.2 Site selection and data collection

For this research Addis Ababa – Adama Expressway was selected according to the available expressway in the country and it is located between 09^0 01' 48" N 38^0 44' 24" E and 08^0 32' 29" N 39^0 16'08" E.

This study was carried out through a series of data collection from four different study sites located on Addis Ababa – Adama Expressway. The data were collected by means of a video technique. During filming sessions, the camera was set up some distance away from the expressway sections to obtain sufficient coverage for the traffic flow.

The site location of Addis Ababa – Adama Expressway shown in Figure 3.1:

<u>Location of Addis Ababa – Adama Expressway</u>

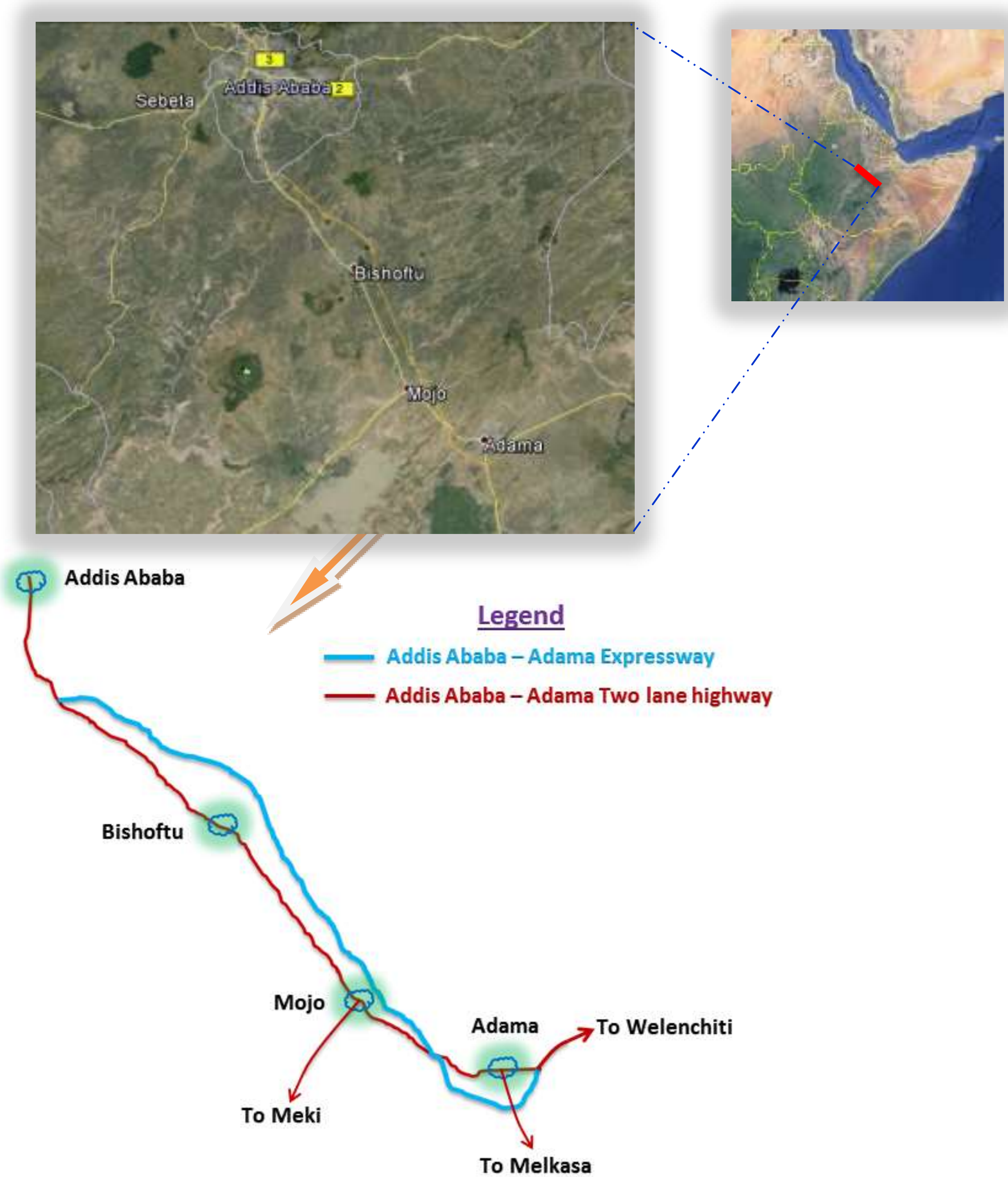


Figure 3.1: Location of Addis Ababa – Adama Expressway (Google Earth)

The main criterion while selecting the data collection sites was the availability of all conditions namely percent grade and length of grade. This criterion was deemed very important for site selection. Also necessary to determine suitable time and time period for collecting data, with the purpose to provide more reliable results.

From the geometrical design of Addis Ababa – Adama expressway the design percent grade, length of grade and chainage was extracted and tabulated shown on Appendix A, then the selection of data was according to the needs and availability (that means longer length of grade with the need of grade percent) on the route outside the influence of merging, diverging, or weaving maneuvers (the influence area of merge segments extends for 1,500 ft downstream of the merge point, the influence area of diverge segments extends for 1,500 ft upstream of the diverge point, and the influence area of weaving segments extends 500 ft upstream and downstream of the segment itself) but the percentage of grade was selected according to the presence in HCM 2010 and the data collection sites are described as follows:

Table 3.1: Selection of chainage according to grade percent and length of grade

For Upgrade		
Upgrade (%)	**Length (Km)**	**Chainage**
≤ 2	1.85	K25 + 810 up to K27 + 660
> 2 - 3	0.83	K55 + 340 up to K56 + 170
> 3 - 4	1.00	K3 + 520 up to K4 + 520
> 4 - 5	1.20	K9 + 260 up to K10 + 460

For Downgrade		
Downgrade (%)	**Length (Km)**	**Chainage**
< 4	0.80	K3 + 520 up to K4 + 520
4 - 5	1.20	K9 + 260 up to K10 + 460

The length of the grade is generally taken from expressway profile. It typically includes the straight portion of the grade plus some portion of the vertical curves at the beginning and end of the grade. It is recommended that 25% of the length of the vertical curves at both ends of the grade be included in the length. Where two consecutive upgrades are present, 50% of the length of the vertical curve joining them is included in the length of each grade according to HCM 2010 and it is shown on the Figure 3.2.

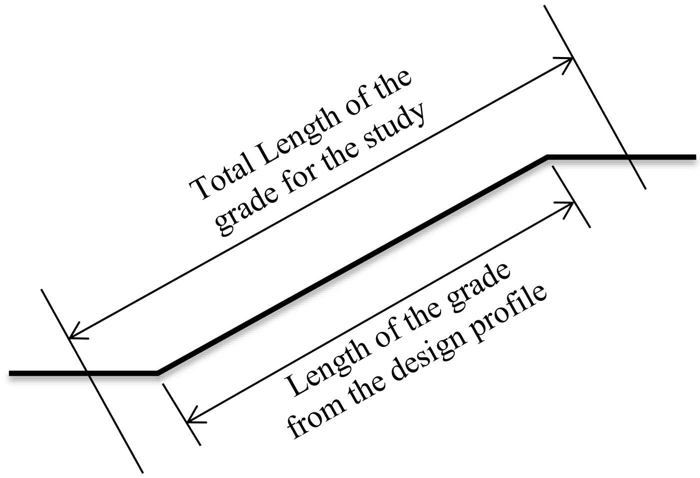


Figure 3.2: Total length of the grade for the study

As shown in Figure 3.2 concept, to collect the field data according to the needs and existing upgrade percent, downgrade percent and grade length with chainage of specific grade percent was tabulated in Table 3.2.

Table 3.2: Chainage and flow direction for the specific grade percent and length of grade

For Upgrade			
Grade (%)	**Length of Grade (Km)**	**Chainage**	**Flow Direction**
≤ 2	0.0 - 0.4	K27 + 413	Adama - Addis Ababa
	> 0.4 - 0.8	K27 + 013	Adama - Addis Ababa
	> 0.8 - 1.2	K26 + 650	Adama - Addis Ababa
	> 1.2 - 1.6	K26 + 213	Adama - Addis Ababa
> 2 - 3	0.0 - 0.4	K55 + 680	Addis Ababa - Adama
	> 0.4 - 0.8	K56 + 070	Addis Ababa - Adama
> 3 - 4	0.0 - 0.4	K3 + 588	Addis Ababa - Adama
	> 0.4 - 0.8	K4 + 050	Addis Ababa - Adama
	> 0.8 - 1.2	K4 + 388	Addis Ababa - Adama
	> 1.2 - 1.6	K4 + 520	Addis Ababa - Adama
> 4 - 5	0.0 - 0.4	K10 + 390	Adama - Addis Ababa
	> 0.4 - 0.8	K9 + 990	Adama - Addis Ababa
	> 0.8 - 1.2	K9 + 660	Adama - Addis Ababa
	> 1.2 - 1.6	K9 + 260	Adama - Addis Ababa

For Downgrade			
Grade (%)	**Length of Grade (Km)**	**Chainage**	**Flow Direction**
< 4	> 0.4 - 0.8	K4 + 050	Adama - Addis Ababa
4 - 5	> 0.8 - 1.2	K9 + 660	Addis Ababa - Adama

The data was collected at stations A, B, C, and D at their specific chainages on upgrade and downgrade as shown on Figure 3.3 according to Table 3.2. But the exact location of the extracted chainage was located in the field by commenced from the known chainage (that is the posted the exact chainage on the road way) and reaches to the exact location of the specific study site.

<u>Study Site A</u>: this section is located on the Addis Ababa – Adama Expressway. The site is situated on the section of expressway between Addis Ababa City and Bishoftu Town. The data collection was done at each four chainage with a traffic flow direction from Addis Ababa to Adama and shown in the Figure 3.3.

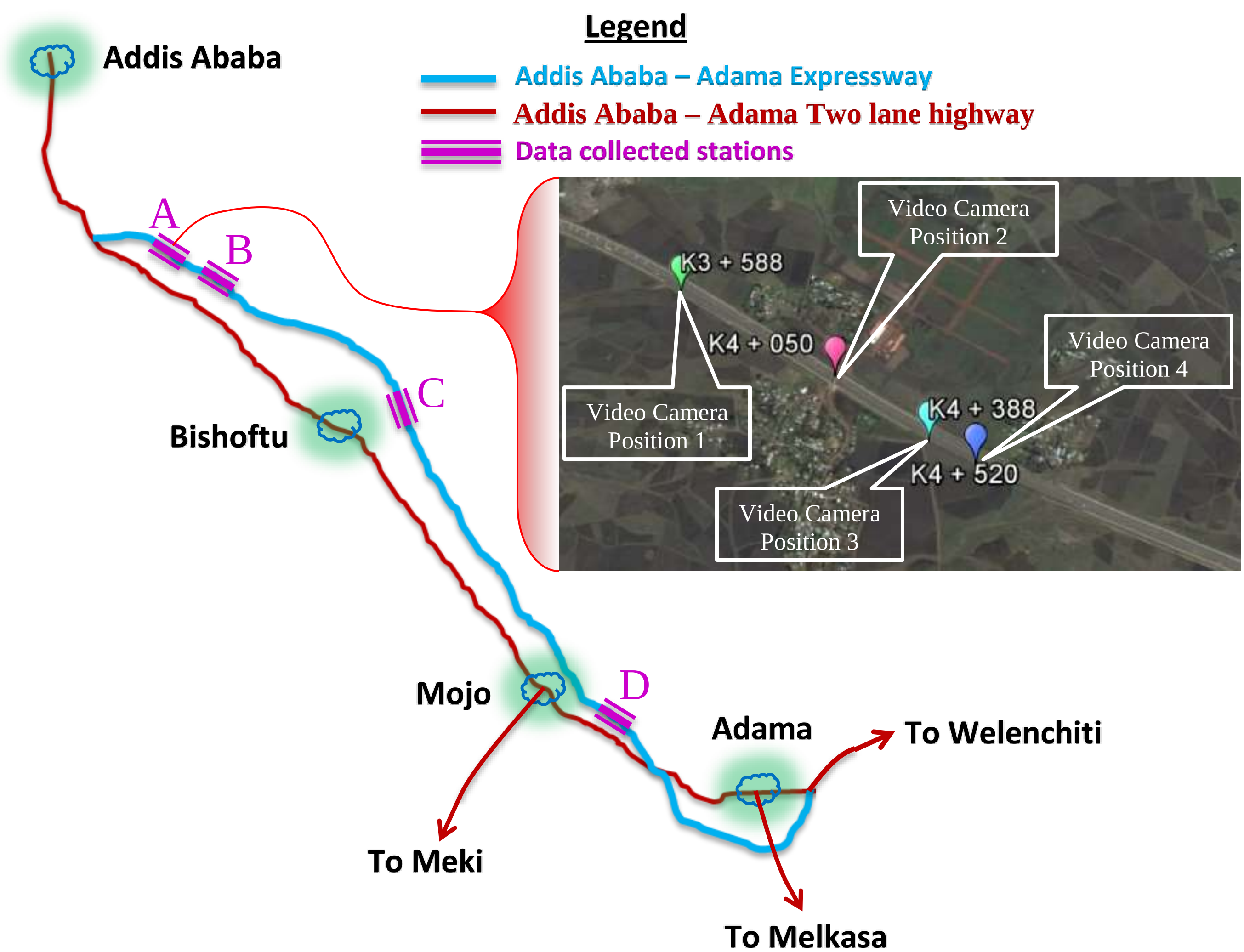


Figure 3.3: Data collected stations on the Addis Ababa – Adama Expressway (Station A)

Study Site B: this section is located on the Addis Ababa – Adama Expressway. The site is situated on the section of expressway between Addis Ababa City and Bishoftu Town. The data collection was done at each four chainage with a traffic flow direction from Adama to Addis Ababa and shown in the Figure 3.4.

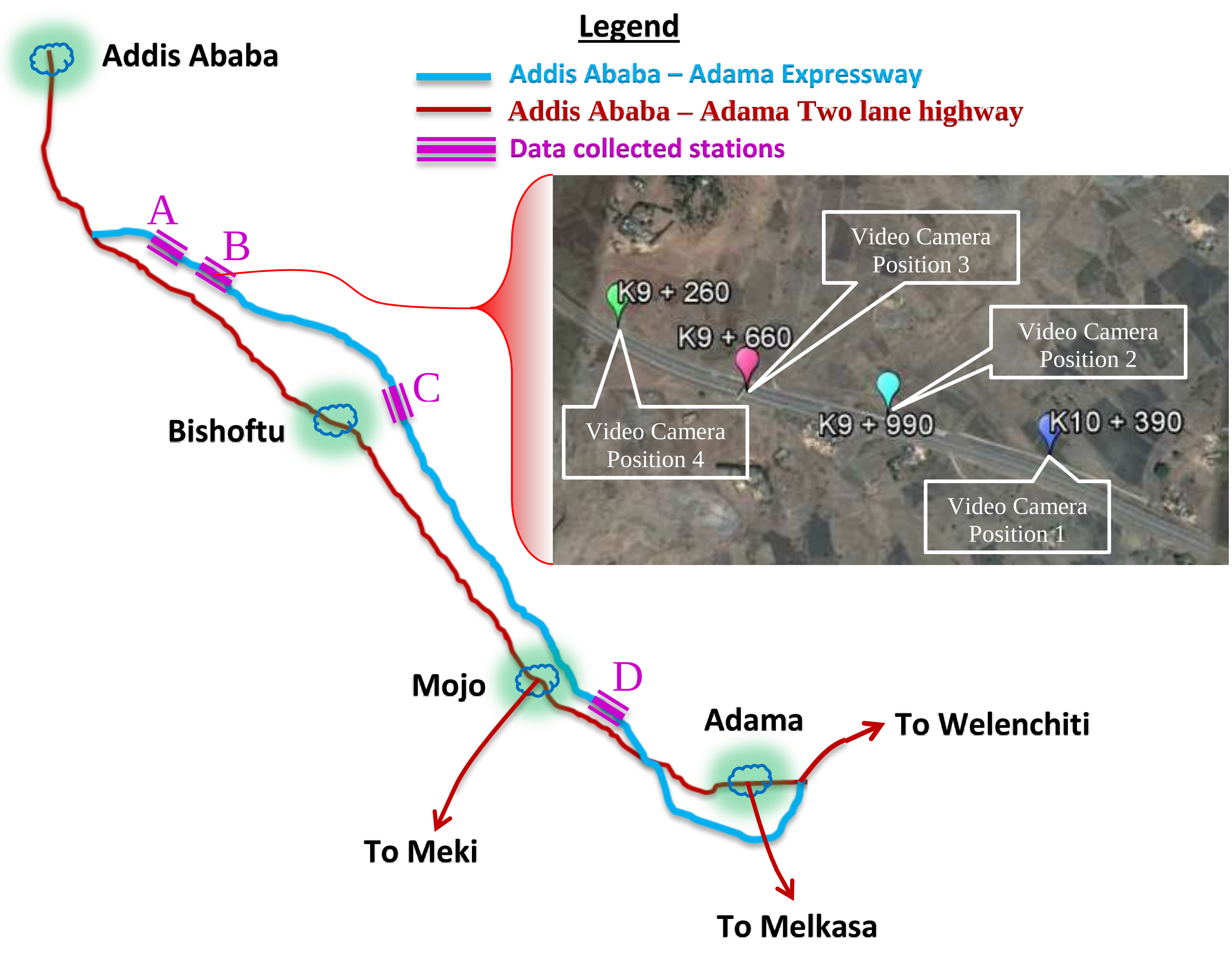


Figure 3.4: Data collected stations on the Addis Ababa – Adama Expressway (Station B)

<u>Study Site C</u>: this section is located on the Addis Ababa – Adama Expressway. The site is situated on the section of expressway between Bishoftu and Mojo towns. The data collection was done at each four chainage with a traffic flow direction from Adama to Addis Ababa and shown in the Figure 3.5.

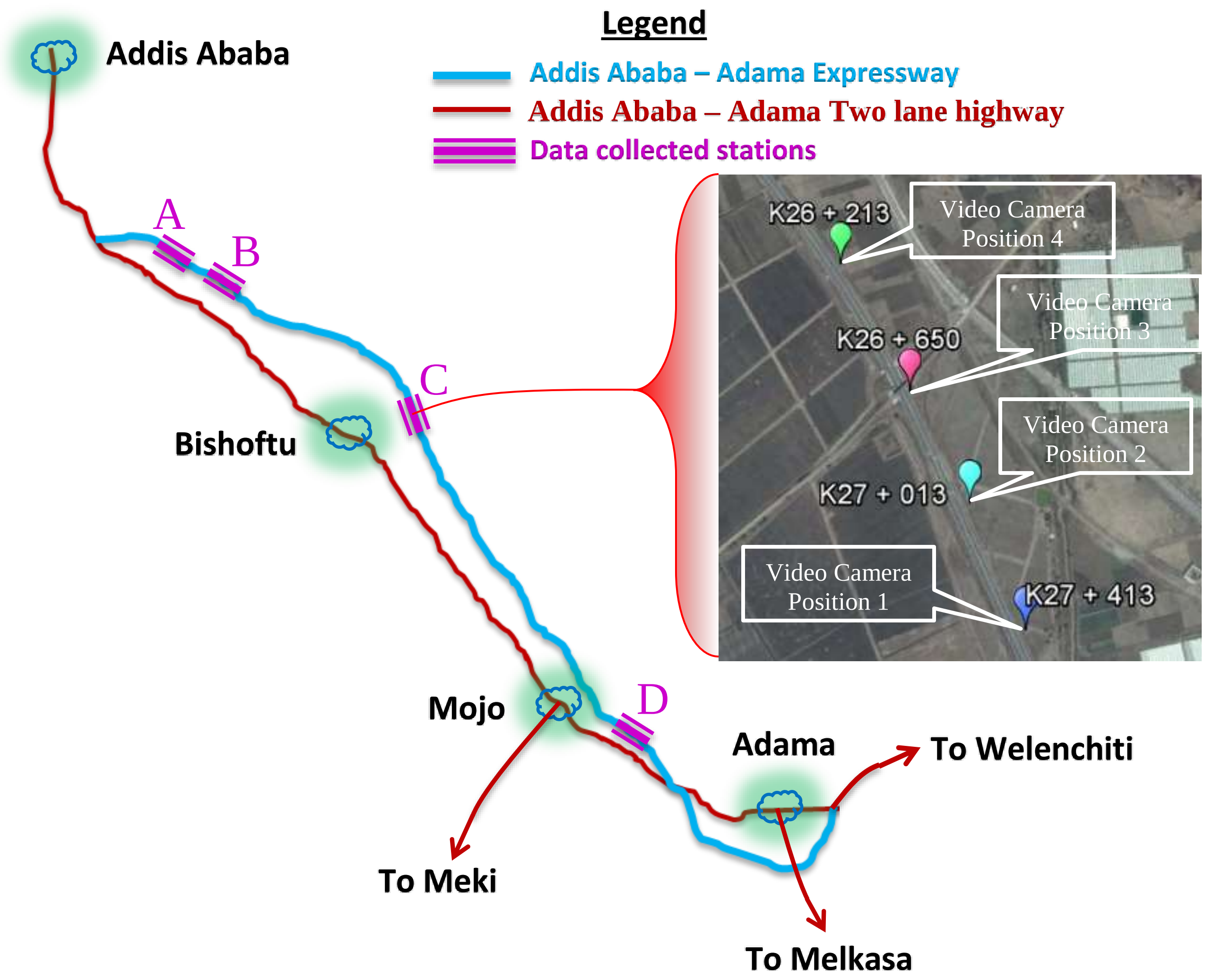


Figure 3.5: Data collected stations on the Addis Ababa – Adama Expressway (Station C)

<u>Study Site D</u>: this section is located on the Addis Ababa – Adama Expressway. The site is situated on the section of expressway between Mojo and Adama towns. The data collection was done at each two chainage with a traffic flow direction from Addis Ababa to Adama and shown in the Figure 3.6.

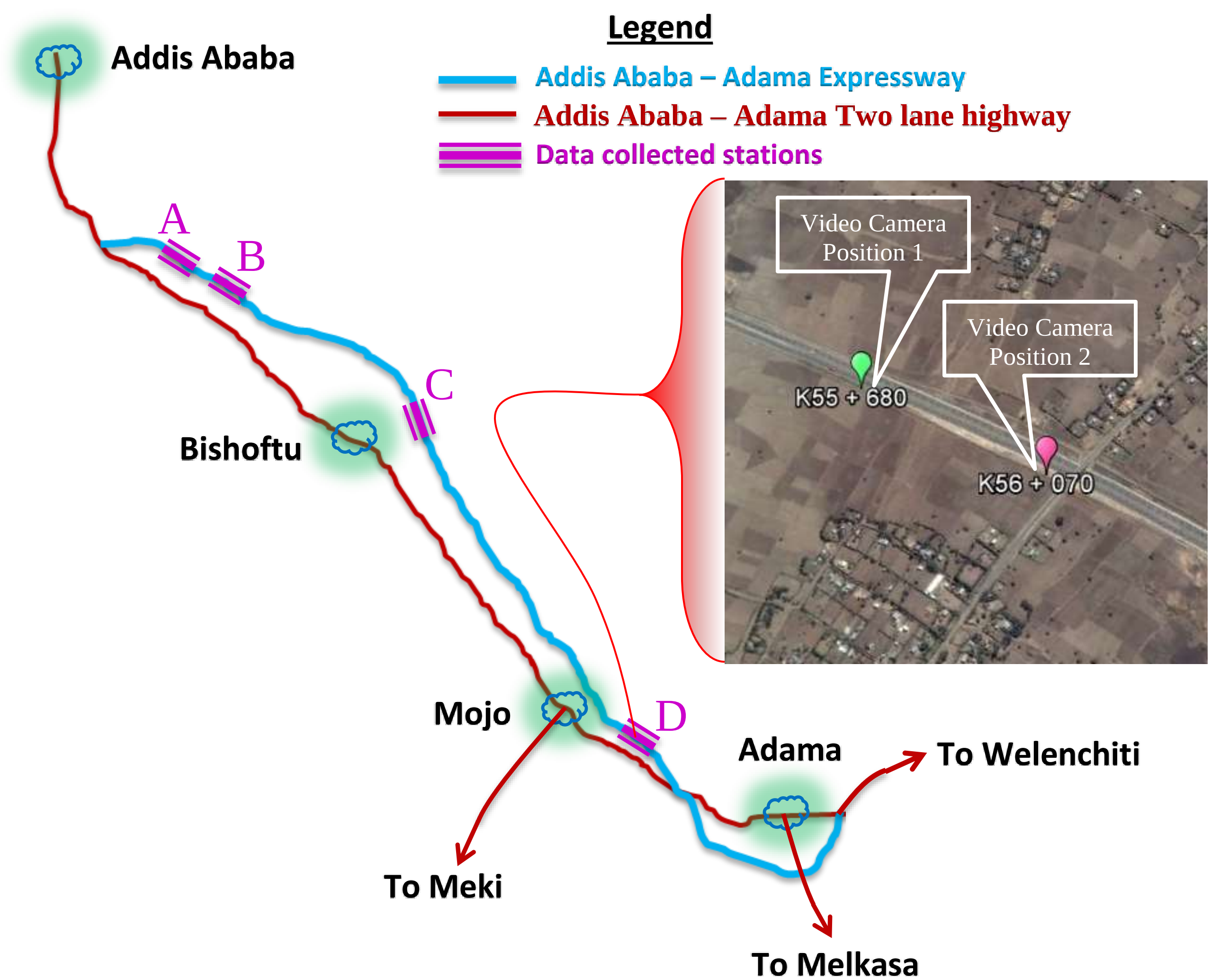


Figure 3.6: Data collected stations on the Addis Ababa – Adama Expressway (Station D)

Table 3.3: Data collected stations with their Co - ordinates

For Upgrade						
Data Collected Stations	**Chainage**	**Co-ordinates**		**Percentage of Grade**	**Length of Grade**	**Flow Direction**
		Easting	**Northing**			
A	K3 + 588	38.83430332	8.85997777	> 3 - 4	0.0 - 0.4	Addis Ababa - Adama
	K4 + 050	38.83836881	8.85818155		> 0.4 - 0.8	
	K4 + 388	38.84076897	8.85676072		> 0.8 - 1.2	
	K4 + 520	38.84189402	8.85631638		> 1.2 - 1.6	
B	K10 + 390	38.88804167	8.83399414	> 4 - 5	0.0 - 0.4	Adama - Addis Ababa
	K9 + 990	38.88439625	8.83449095		> 0.4 - 0.8	
	K9 + 660	38.88123711	8.83465712		> 0.8 - 1.2	
	K9 + 260	38.87811350	8.83584104		> 1.2 - 1.6	
C	K27 + 413	39.01289280	8.76472417	≤ 2	0.0 - 0.4	Adama - Addis Ababa
	K27 + 013	39.01229844	8.76824991		> 0.4 - 0.8	
	K26 + 650	39.01148691	8.77153807		> 0.8 - 1.2	
	K26 + 213	39.01048685	8.77541367		> 1.2 - 1.6	
D	K55 + 680	39.17505489	8.57750387	> 2 - 3	0.0 - 0.4	Addis Ababa - Adama
	K56 + 070	39.17759641	8.57522185		> 0.4 - 0.8	

For Downgrade						
Data Collected Stations	**Chainage**	**Co-ordinates**		**Percentage of Grade**	**Length of Grade**	**Flow Direction**
		Easting	**Northing**			
A	K4 + 050	38.83836881	8.85818155	< 4	> 0.4 - 0.8	Adama - Addis Ababa
B	K9 + 660	38.88123711	8.83465712	4 - 5	> 0.8 - 1.2	Addis Ababa - Adama

After knowing the locations where the data was taken, then determined when the data was taken by using previously recorded data from the database. By adding the consecutive 15-minutes recorded data for one hour and proceeding by shifting 15-minutes for the rest of hours, the peak hour volume was determined from the previously recorded data.

6:00 AM – 6:15 AM → number of vehicles, X_1

6:15 AM – 6:30 AM → number of vehicles, X_2

6:30 AM – 6:45 AM → number of vehicles, X_3

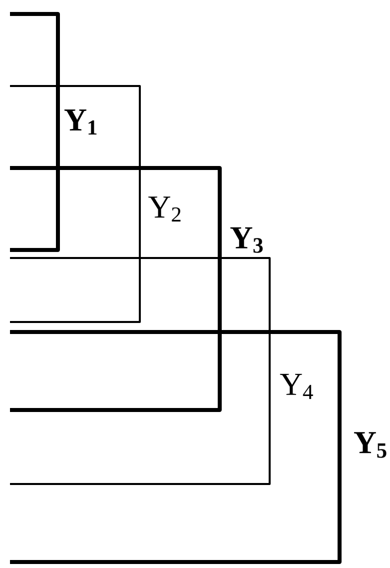
6:45 AM – 7:00 AM → number of vehicles, X_4

7:00 AM – 7:15 AM → number of vehicles, X_5

7:15 AM – 7:30 AM → number of vehicles, X_6

7:30 AM – 7:45 AM → number of vehicles, X_7

7:45 AM – 8:00 AM → number of vehicles, X_8



---------- continue with the above pattern up to X_n.

$Y_1 = X_1 + X_2 + X_3 + X_4$

$Y_2 = X_2 + X_3 + X_4 + X_5$

$Y_3 = X_3 + X_4 + X_5 + X_6$

$Y_4 = X_4 + X_5 + X_6 + X_7$

$Y_5 = X_5 + X_6 + X_7 + X_8$

---------- continue with the above pattern up to Y_n.

So with this pattern the peak hour volume was determined and illustrated graphically in the Figure 3.7 up to Figure 3.12.

Figure 3.7 shows the peak hour volume that the vehicles passed chainage K27 + 413, K27 + 013, K9 + 660, K9 + 260 and K4 + 050 on 04/12/2016 from Adama to Addis Ababa direction of flow. The peak hour volume observed from the 15-minutes period interval from the data at 12:00:00 PM and at 05:30:00 PM was 378 vehicles/hour and 489 vehicles/hour respectively. However, the convenient data collection peak hour volume was selected at 12:00:00 PM.

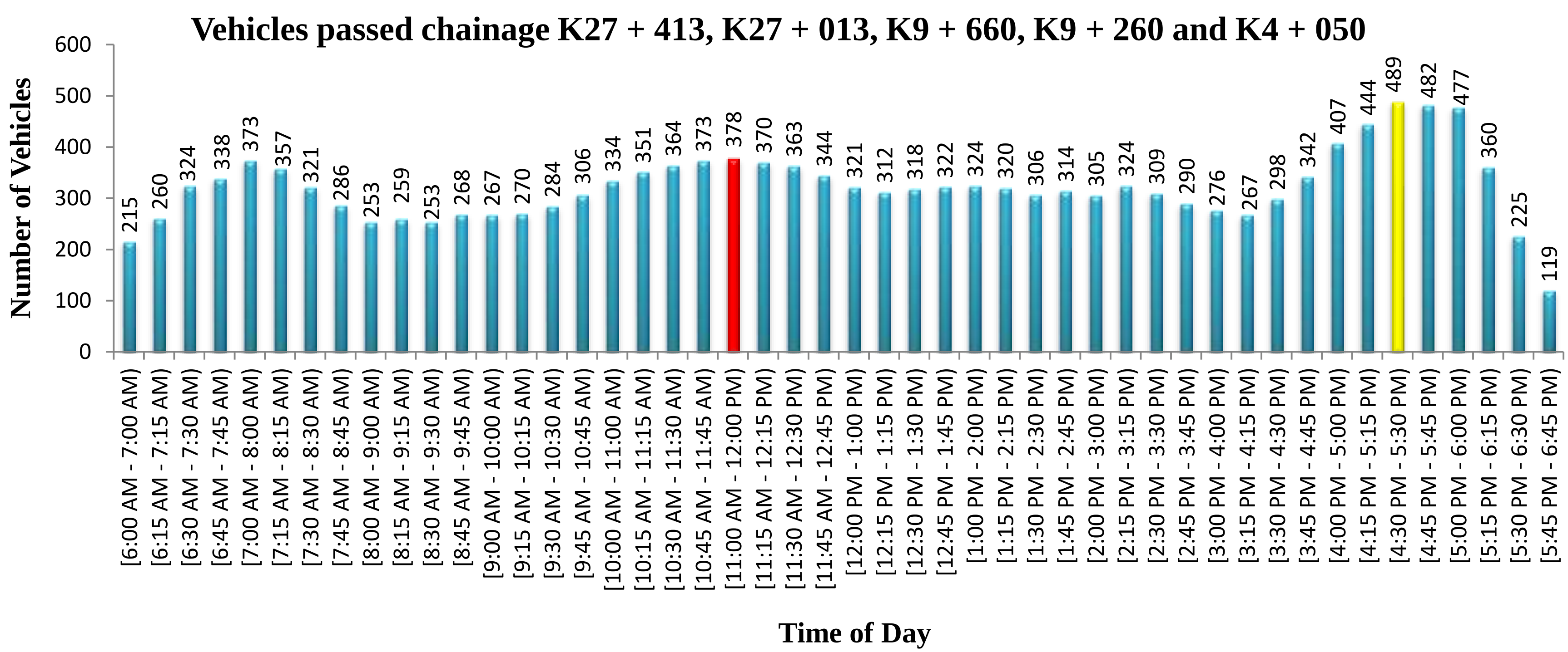


Figure 3.7: Vehicles passed K27 + 413, K27 + 013, K9 + 660, K9 + 260 and K4 + 050 from Adama to Addis Ababa direction of flow

Figure 3.8 shows the peak hour volume that the vehicles passed chainage K26 + 650 and K26 + 213 on 04/13/2016 from Adama to Addis Ababa direction of flow. The peak hour volume observed from the 15-minutes period interval from the data at 08:15:00 AM, at 12:00:00 PM and at 06:00:00 PM was 414 vehicles/hour, 363 vehicles/hour and 441 vehicles/hour respectively. However, the convenient data collection peak hour volume was selected at 12:00:00 PM.

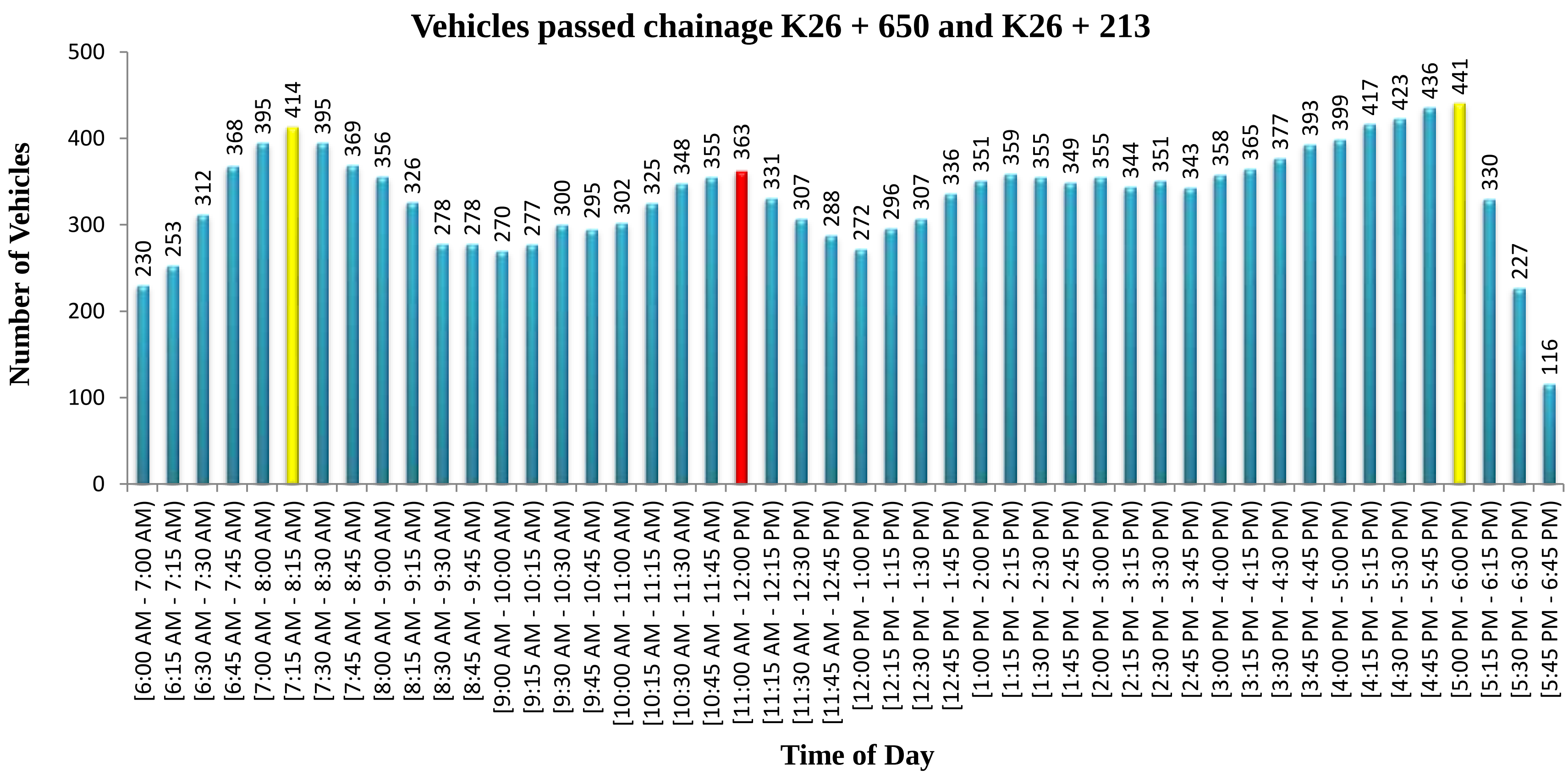


Figure 3.8: Vehicles passed K26 + 213 and K26 + 650 from Adama to Addis Ababa direction of flow

Figure 3.9 shows the peak hour volume that the vehicles passed chainage K55 + 680 and K56 + 070 on 04/14/2016 from Addis Ababa to Adama direction of flow. The peak hour volume observed from the 15-minutes period interval from the data at 03:00:00 PM and at 06:00:00 PM was 290 vehicles/hour and 293 vehicles/hour respectively. However, the convenient data collection peak hour volume was selected at 03:00:00 PM.

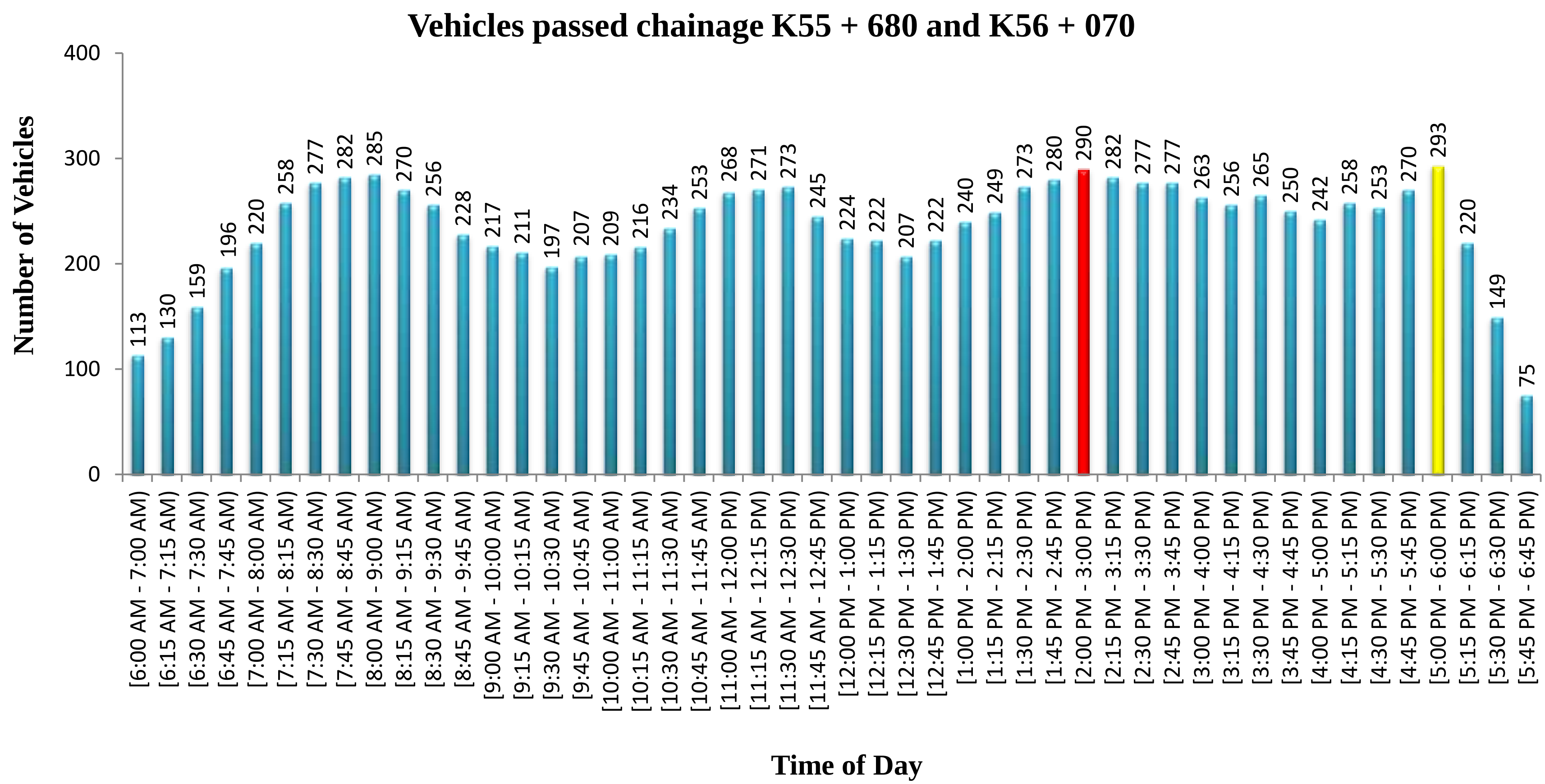


Figure 3.9: Vehicles passed K55 + 680 and K56 + 070 from Addis Ababa to Adama direction of flow

Figure 3.10 shows the peak hour volume that the vehicles passed chainage K3 + 588, K4 + 050 and K9 + 660 on 04/12/2016 from Addis Ababa to Adama direction of flow. The peak hour volume observed from the 15-minutes period interval from the data at 11:15:00 AM was 456 vehicles/hour and the data collected at 11:15:00 AM peak hour volume.

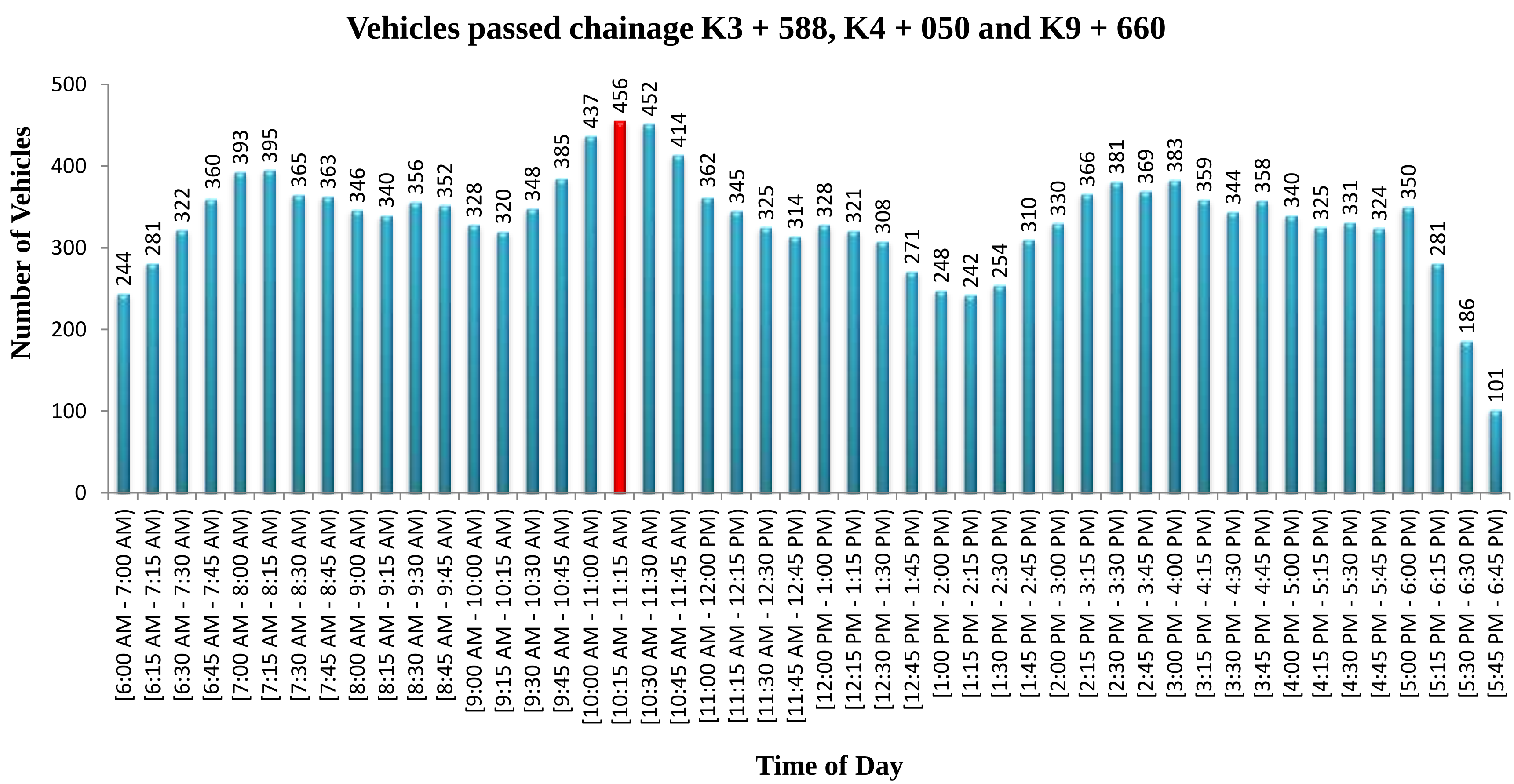


Figure 3.10: Vehicles passed K3 + 588, K4 + 050 and K9 + 660 from Addis Ababa to Adama direction of flow

Figure 3.11 shows the peak hour volume that the vehicles passed chainage K4 + 388 and K4 + 520 on 04/13/2016 from Addis Ababa to Adama direction of flow. The peak hour volume observed from the 15-minutes period interval from the data at 11:30:00 AM was 471 vehicles/hour and the data collected at 11:30:00 AM peak hour volume.

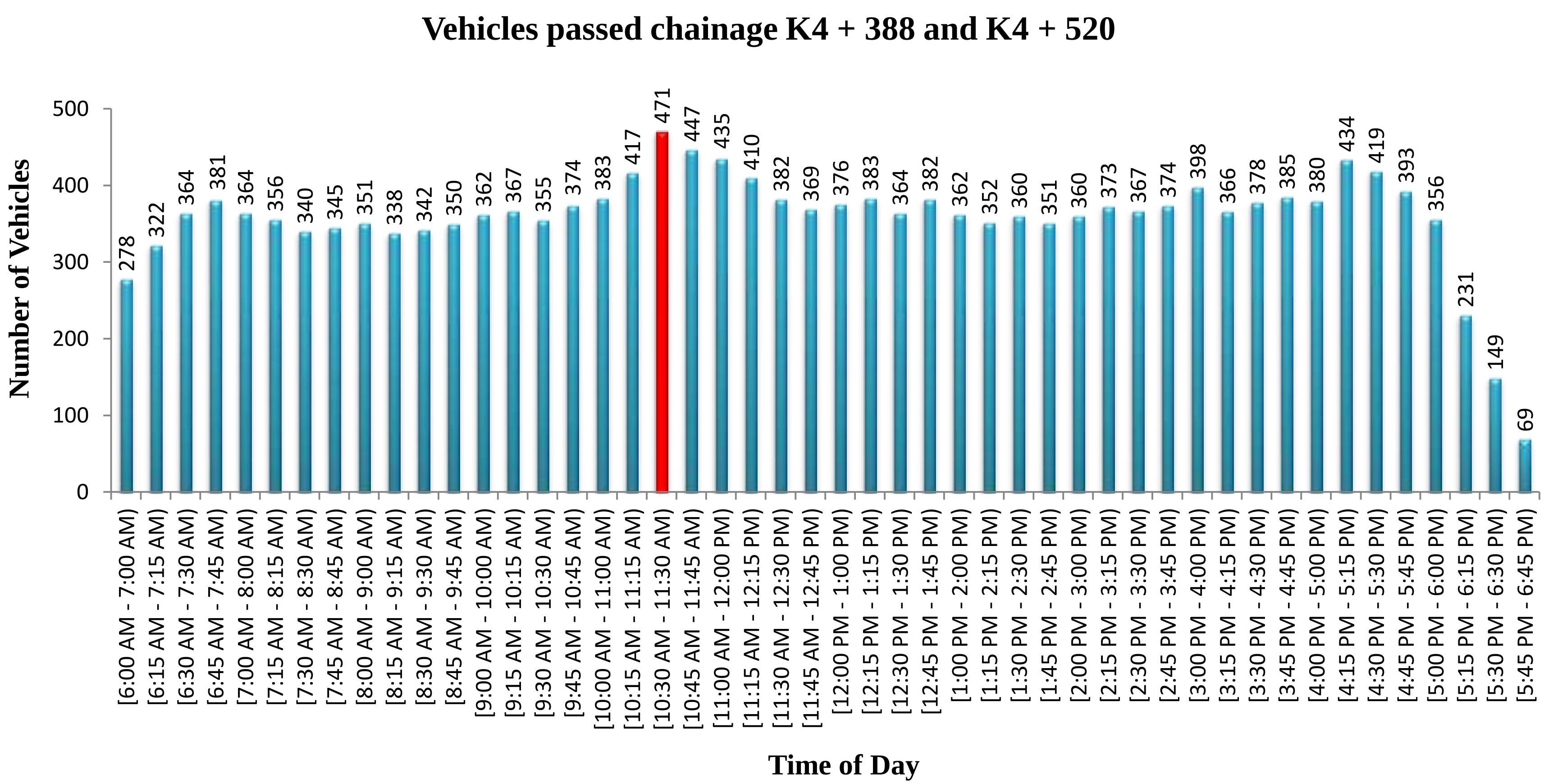


Figure 3.11: Vehicles passed K4 + 388 and K4 + 520 from Addis Ababa to Adama direction of flow

Figure 3.12 shows the peak hour volume that the vehicles passed chainage K10 + 390 and K9 + 990 on 04/14/2016 from Adama to Addis Ababa direction of flow. The peak hour volume observed from the 15-minutes period interval from the data at 11:30:00 AM and at 06:00:00 PM was 361 vehicles/hour and 503 vehicles/hour respectively. However, the convenient data collection peak hour volume was selected at 11:30:00 AM.

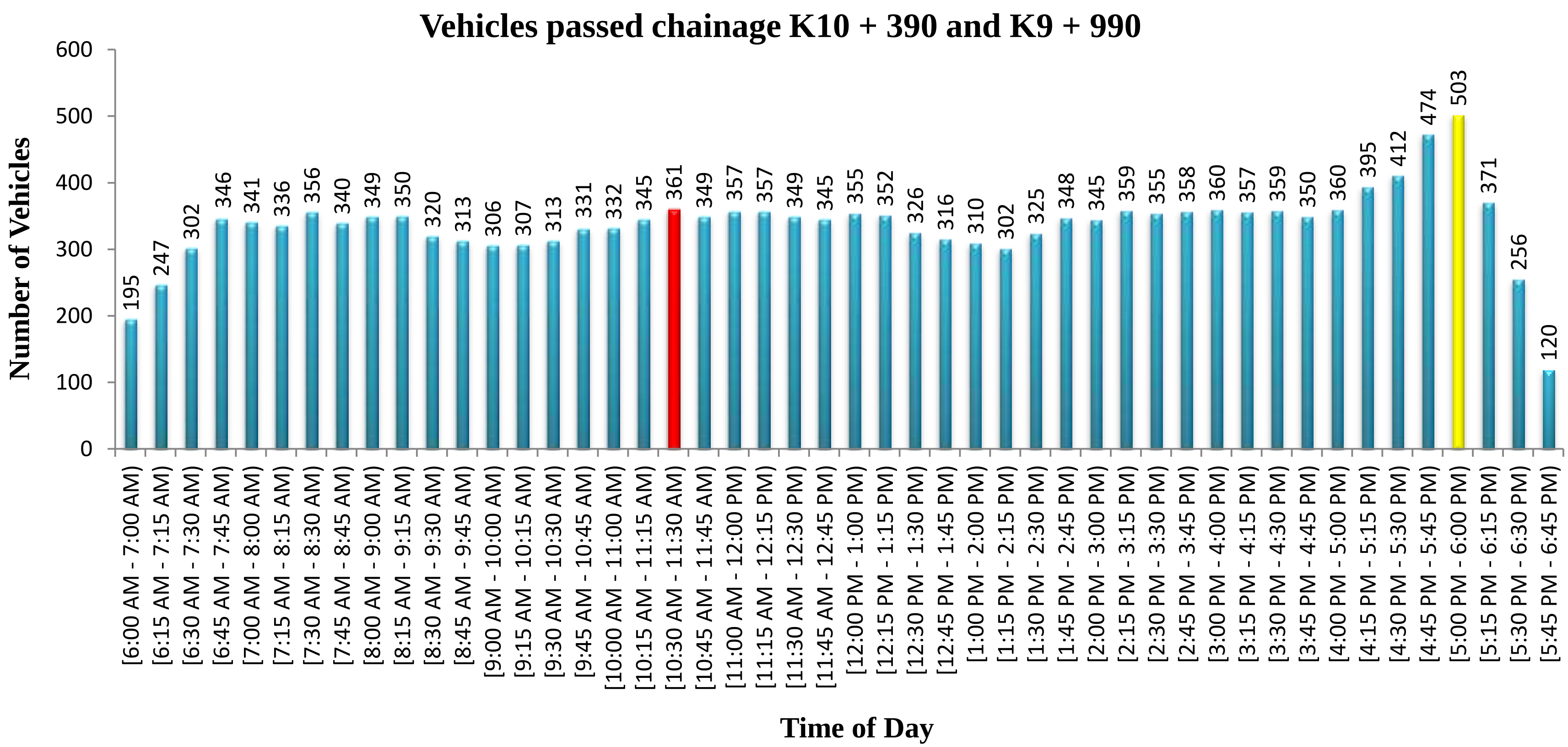


Figure 3.12: Vehicles passed K10 + 390 and K9 + 990 from Adama to Addis Ababa direction of flow

After determined where the location and at what time the data was collected, went to the site and selected the appropriate position to take the video record for the needs in percent grade and length of grade mentioned in Table 3.3. The video record was taken for consecutive three hours; one hour before peak hour, one hour on peak hour, one hour after peak hour. And also the camera was set-up at least fifteen minutes before the start of each recording. So, the data was collected in the field by using a portable video camera, distance measuring meter, plastic cone and GPS (Global Positioning System) and also Data collection sheet was used and the Free Flow Speed was determined by using distance and time measurement on station K26 + 650 and the data transcribe and tabulated.

Table 3.4: Data collected in the field with location and time

For Upgrade

Data Collected Stations	Chainage	Co-ordinates		Percentage of Grade	Length of Grade	Date of Collection	Time of Collection		Flow Direction
		Easting	Northing				Start	End	
A	K3 + 588	38.83430332	8.85997777	> 3 - 4	0.0 - 0.4	May 10, 2016	9:15 AM	12:15 PM	Addis Ababa - Adama
	K4 + 050	38.83836881	8.85818155		> 0.4 - 0.8				
	K4 + 388	38.84076897	8.85676072		> 0.8 - 1.2	May 11, 2016	9:30 AM	12:30 PM	
	K4 + 520	38.84189402	8.85631638		> 1.2 - 1.6				
B	K10 + 390	38.88804167	8.83399414	> 4 - 5	0.0 - 0.4	May 19, 2016	9:30 AM	12:30 PM	Adama - Addis Ababa
	K9 + 990	38.88439625	8.83449095		> 0.4 - 0.8				
	K9 + 660	38.88123711	8.83465712		> 0.8 - 1.2	May 24, 2016	10:00 AM	1:00 PM	
	K9 + 260	38.87811350	8.83584104		> 1.2 - 1.6				
C	K27 + 413	39.01289280	8.76472417	≤ 2	0.0 - 0.4	May 17, 2016	10:00 AM	1:00 PM	Adama - Addis Ababa
	K27 + 013	39.01229844	8.76824991		> 0.4 - 0.8				
	K26 + 650	39.01148691	8.77153807		> 0.8 - 1.2	May 18, 2016	10:00 AM	1:00 PM	
	K26 + 213	39.01048685	8.77541367		> 1.2 - 1.6				
D	K55 + 680	39.17505489	8.57750387	> 2 - 3	0.0 - 0.4	May 12, 2016	1:00 PM	4:00 PM	Addis Ababa - Adama
	K56 + 070	39.17759641	8.57522185		> 0.4 - 0.8				

For Downgrade

Data Collected Stations	Chainage	Co-ordinates		Percentage of Grade	Length of Grade	Date of Collection	Time of Collection		Flow Direction
		Easting	Northing				Start	End	
A	K4 + 050	38.83836881	8.85818155	< 4	> 0.4 - 0.8	May 10, 2016	9:15 AM	12:15 PM	Adama - Addis Ababa
B	K9 + 660	38.88123711	8.83465712	4 - 5	> 0.8 - 1.2	May 24, 2016	10:00 AM	1:00 PM	Addis Ababa - Adama

3.3 Data analysis

After the finishing of field data collection, the raw data reduced to homogeneous category and tabulated, the proportion of percentage of trucks and buses on upgrade 10, 15, 20, 25, 30, 35, 40, 45 and 50 percent and the percentage of trucks and buses on downgrade 10, 15, 20, 25, 30, 35, 40, 45 and 50 percent extracted from the recorded video and also the base flow rate and mixed flow rate is determined by assigning numerals and symbols. The total video record for one station was three consecutive hours but for analysis fifteen minutes was used but also the fifteen minutes did not fulfill the need of percentages of trucks and buses. So, according to Roess, 2004, "*Rates of flow can be computed for any period of time and researchers often use rates for periods of one to five minutes*" then to fulfill the remaining needs of percentages of trucks and buses, one to five minutes of flow data was used.

The next step was inserting the extracted flow data values for every percent of grade and proportion of trucks and buses in the following relationship formula to determine Passenger Car Equivalents. The flow of a passenger car only traffic stream may be related to the flow of a mixed traffic stream using an aggregate PCE and formulated as (Ingle, 2004):

$$q_B = (1 - \sum_i^n P_i) q_M + \sum_i^n P_i \,.\, E_T \,.\, q_M \qquad [3.1]$$

Then dividing by q_M and subtracting 1 from both sides gives

$$\frac{q_B}{q_M} - 1 = \sum_i^n P_i \,(E_T - 1) \qquad [3.2]$$

And then dividing by $\sum_i^n P_i$ and adding 1 for both sides gives

$$E_T = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1 \qquad [3.3]$$

Where: E_T = passenger equivalent of trucks

P_i = Proportion of trucks of type i out of all trucks n in the mixed traffic flow

q_B = base flow rate (passenger cars only)

q_M = mixed flow rate (passenger cars + trucks)

Figure 3.13 illustrates the foregoing approach to the research

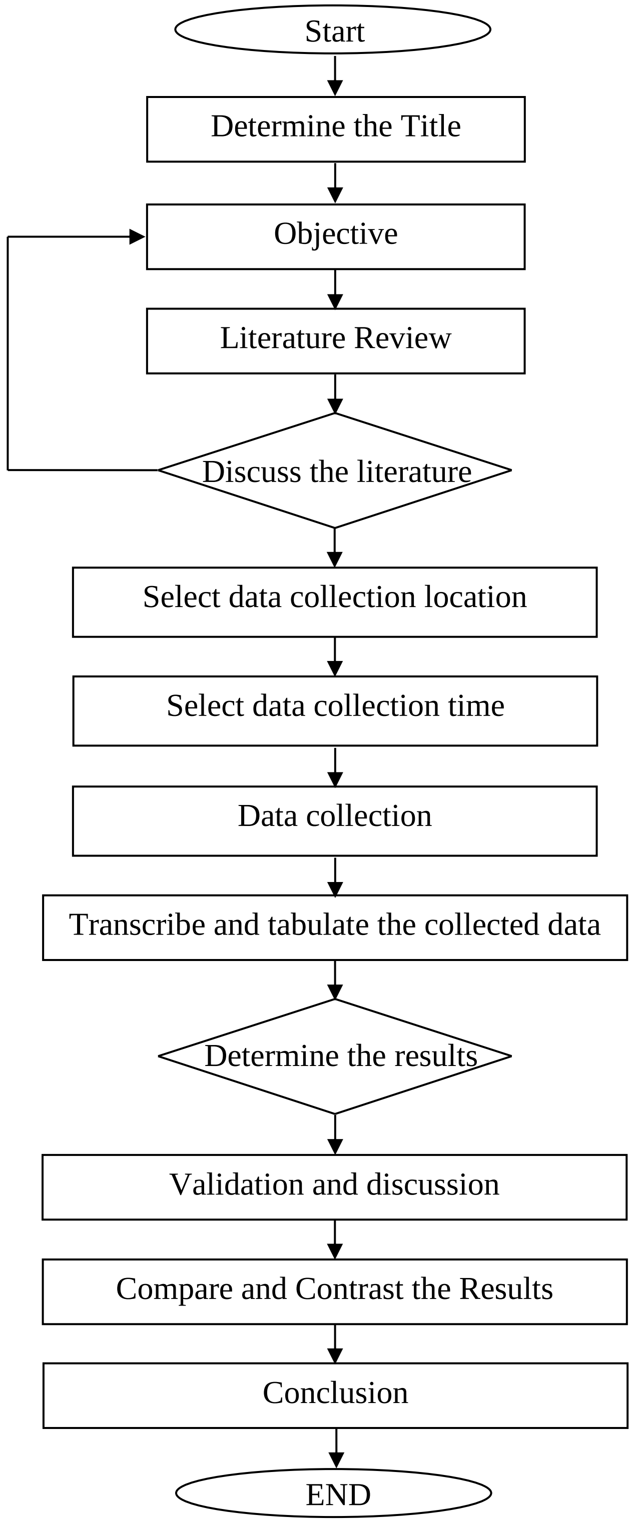


Figure 3.13: Research flow chart

Chapter 4. Results and Discussions

4.1 Overview

According to Ethiopian Roads Authority (ERA) classified vehicles into thirteen classes. Based on a measure of the damaging effect of vehicle axles that is Equivalent Standard Axels (ESA) from class one up to class two classified as passenger car and from class three up to class thirteen classified as heavy vehicles as illustrated on Table 2.3: Vehicle Classification.

In this study the proportion of trucks and buses conducted in nine different percentages corresponding to grade percent and length of grade that is at ten, fifteen, twenty, twenty-five, thirty, thirty-five, forty, forty-five and fifty percent.

The data collection sheet was used for collection of data shown in Appendix B, and the Free Flow Speed data was transcribe and tabulated shown in Appendix C. According to the collected data the proportion of trucks and buses, base flow rate and mixed flow rate was determined and summarized shown in Appendix D. then by using Flow Density Method the Passenger Car Equivalent was determined and tabulated in Table 4.1 for upgrades and Table 4.2 for downgrade. In Appendix E was shown the sample calculation to determine Passenger Car Equivalents.

4.2 Results of PCE

4.2.1 Variability of Trucks Proportion by PCE

The proportion of trucks and buses in HCM 2010 includes from 2 % up to $\geq$ 25% and in this study the proportion of trucks considered from 10% up to 50%. So for comparison the truck proportion from 10% up to 50 % matched with the HCM 2010.

One of the purposes this study is that, PCE value increases as the proportion of trucks and buses decreases and this mode is observed in HCM 2010. In the calculated PCE, based on Flow Density method the proportions of trucks and buses have a substantial effect in the traffic flow and illustrated in Figure 4.1 up to Figure 4.10.

From Figure 4.1 up to Figure 4.10 the trucks and buses proportion increases the PCE decreases up to 50 % of trucks and buses proportion non-linearly because the interaction between trucks and buses with passenger cars decreases so trucks and buses form a platoon while climbing the grade. And the interaction between trucks and buses with trucks and buses is insignificant since the trucks perform almost the same performance due to this the variation of PCE at 50 % proportion of trucks and buses shows little variability.

The proportion of trucks and buses decreases the executed PCE value increases and the executed PCE value was higher than the value provided in HCM 2010 up to 50 % proportion of trucks and buses, so this difference may be due to the performance of the vehicles, the geometrical design, the traffic flow characteristics, restriction of lane and behavior of drivers as compared with the other places or countries.

Figure 4.1 shows variability PCE by trucks and buses proportion for 0.0 - 0.4 km grade length and ≤ 2 % upgrade by using Flow Density method.

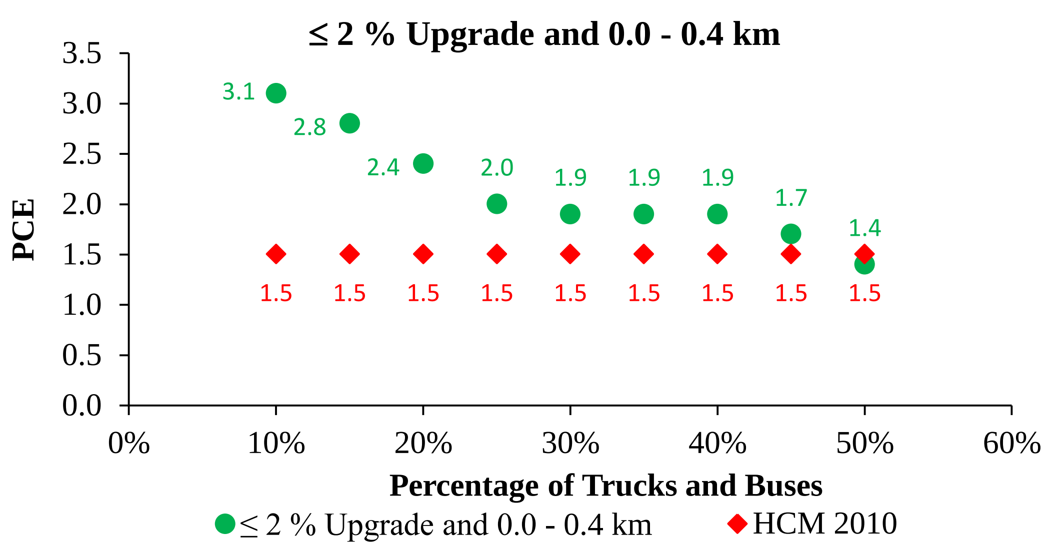


Figure 4.1: PCE Variability by truck proportion, 0.0 - 0.4 km grade length and ≤ 2 % upgrade

Figure 4.2 shows variability PCE by trucks and buses proportion for > 0.4 – 0.8 km grade length and ≤ 2 % upgrade by using Flow Density method.

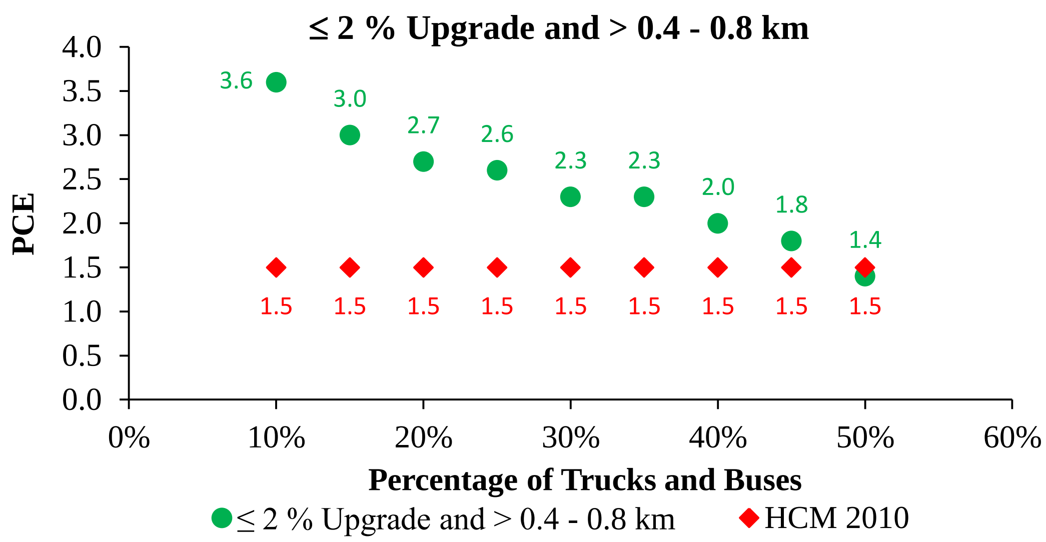


Figure 4.2: PCE Variability by truck proportion, > 0.4 - 0.8 km grade length and ≤ 2 % upgrade

Figure 4.3 shows variability PCE by trucks and buses proportion for > 0.8 – 1.2 km grade length and ≤ 2 % upgrade by using Flow Density method.

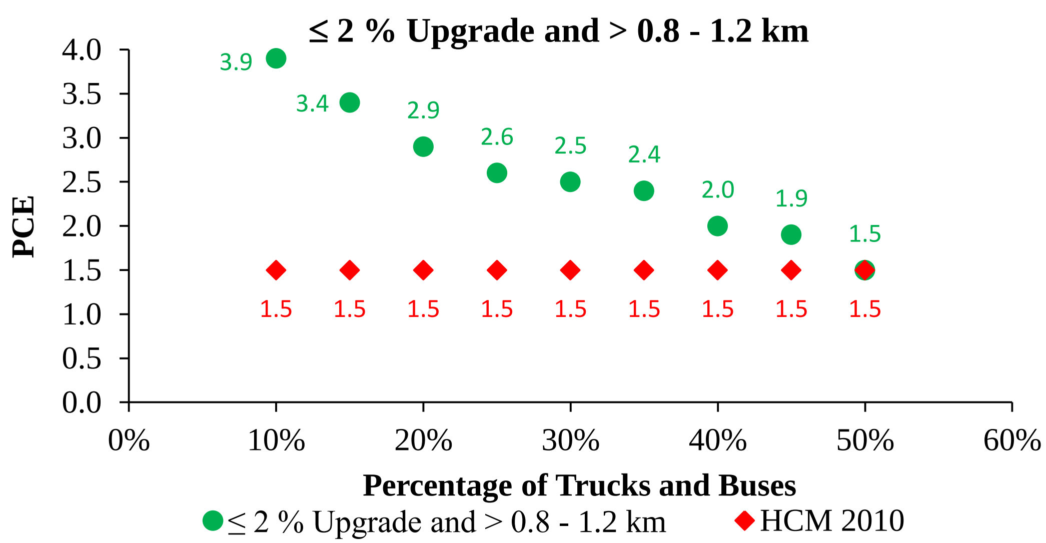


Figure 4.3: PCE Variability by truck proportion, > 0.8 - 1.2 km grade length and ≤ 2 % upgrade

Figure 4.4 shows variability PCE by trucks proportion for > 1.2 – 1.6 km grade length and ≤ 2 % upgrade by using Flow Density method.

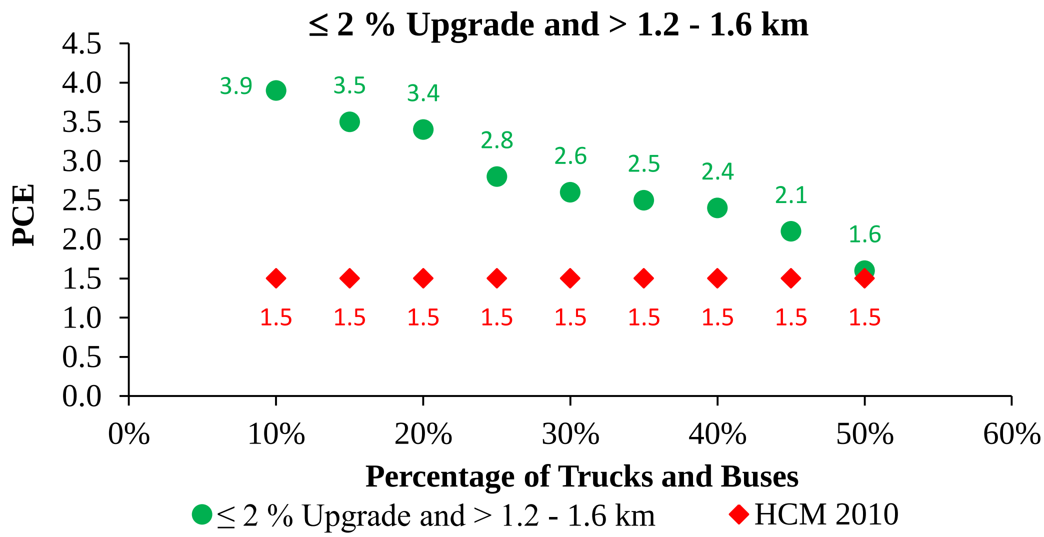


Figure 4.4: PCE Variability by truck proportion, >1.2 - 1.6 km grade length and ≤ 2 % upgrade

Figure 4.5 shows variability PCE by trucks and buses proportion for 0.0 – 0.4 km grade length and > 3 – 4 % upgrade by using Flow Density method.

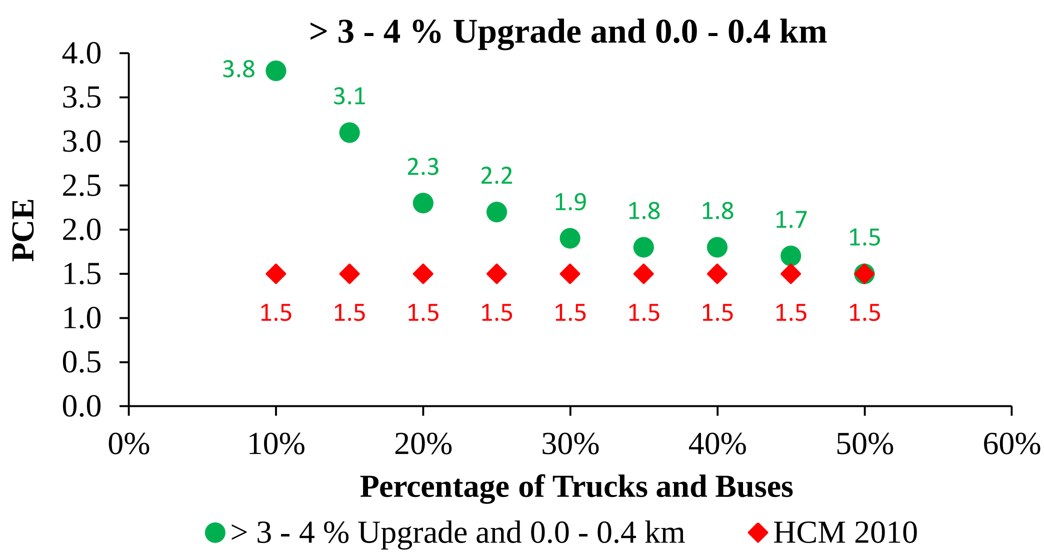


Figure 4.5: PCE Variability by truck proportion, 0.0 - 0.4 km grade length and > 3-4 % upgrade

Figure 4.6 shows variability PCE by trucks and buses proportion for > 0.4 – 0.8 km grade length and > 3 – 4 % upgrade by using Flow Density method.

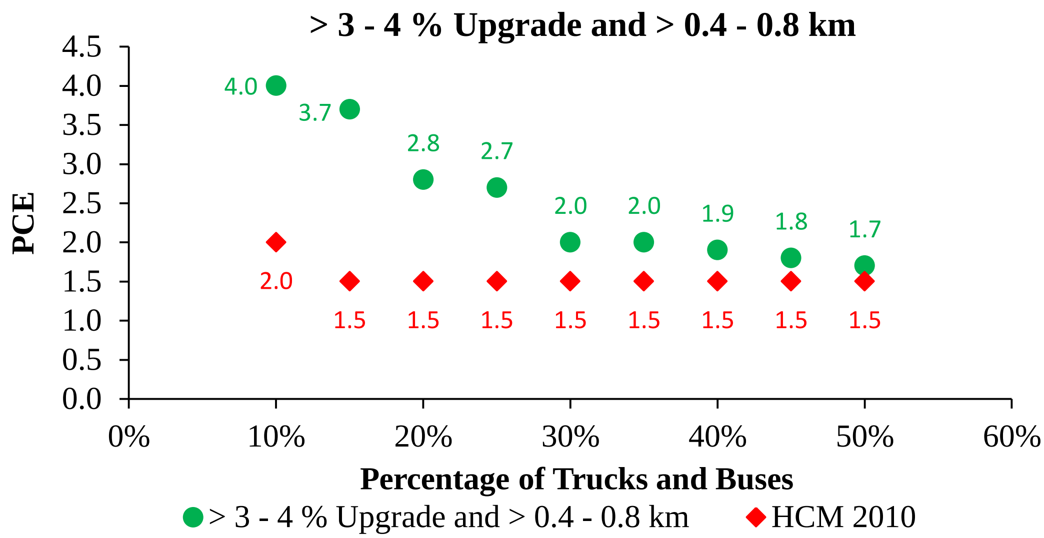


Figure 4.6: PCE Variability by truck proportion, > 0.4 - 0.8 km grade length and > 3-4 % upgrade

Figure 4.7 shows variability PCE by trucks and buses proportion for > 0.8 – 1.2 km grade length and > 3 – 4 % upgrade by using Flow Density method.

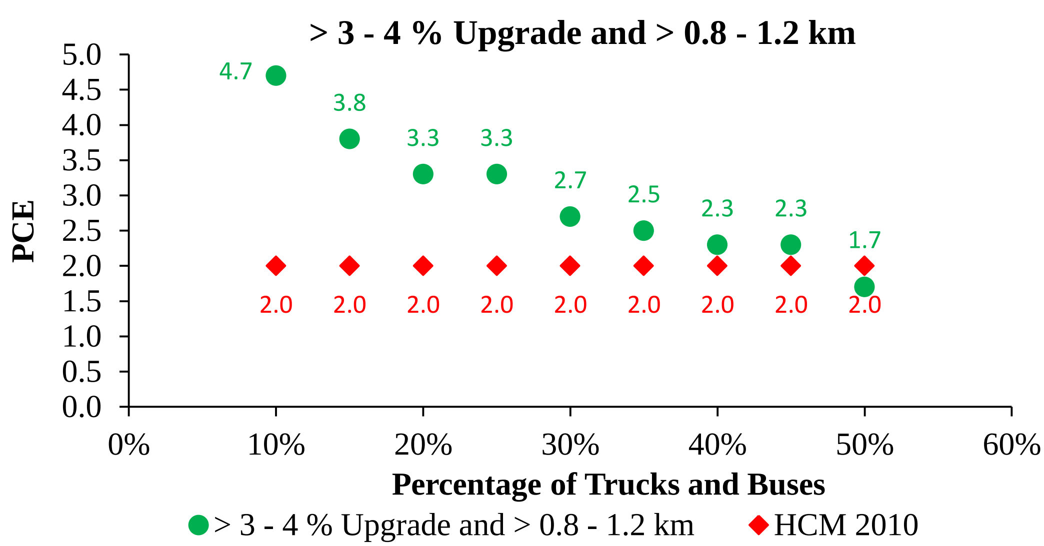


Figure 4.7: PCE Variability by truck proportion, > 0.8 - 1.2 km grade length and > 3-4 % upgrade

Figure 4.8 shows variability PCE by trucks and buses proportion for > 1.2 – 1.6 km grade length and > 3 – 4 % upgrade by using Flow Density method.

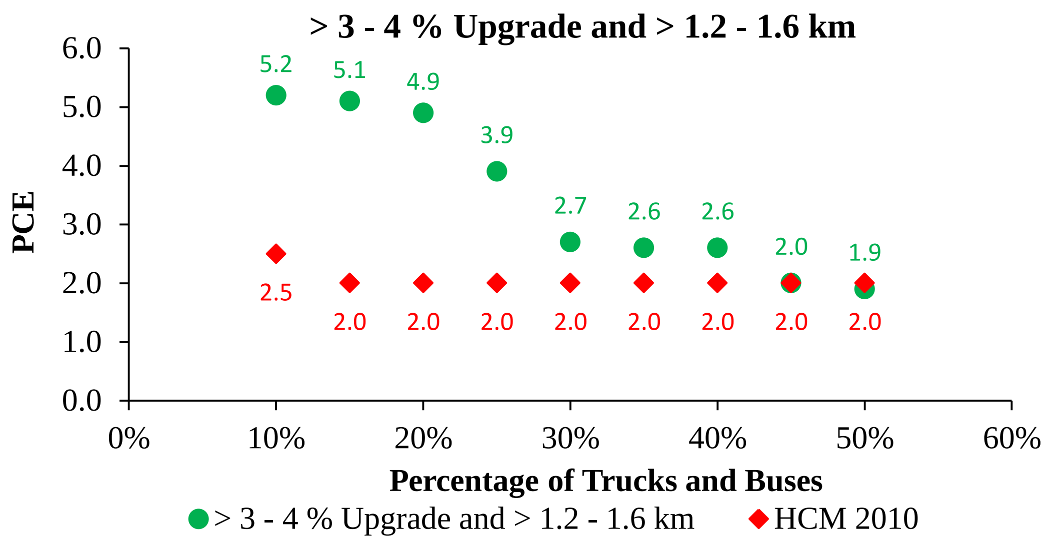


Figure 4.8: PCE Variability by truck proportion, > 1.2 - 1.6 km grade length and > 3-4 % upgrade

Figure 4.9 shows variability PCE by trucks and buses proportion for ≤ 0.8 km grade length and < 4 % downgrade by using Flow Density method.

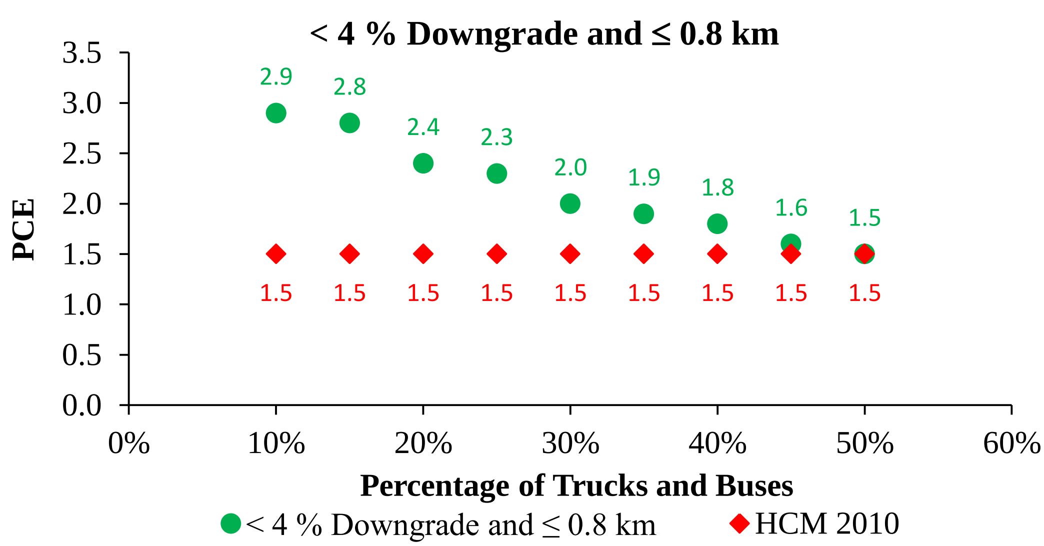


Figure 4.9: PCE Variability by truck proportion, ≤ 0.8 km grade length and < 4 % downgrade

Figure 4.10 shows variability PCE by trucks and buses proportion for ≤ 1.2 km grade length and 4 – 5 % downgrade by using Flow Density method.

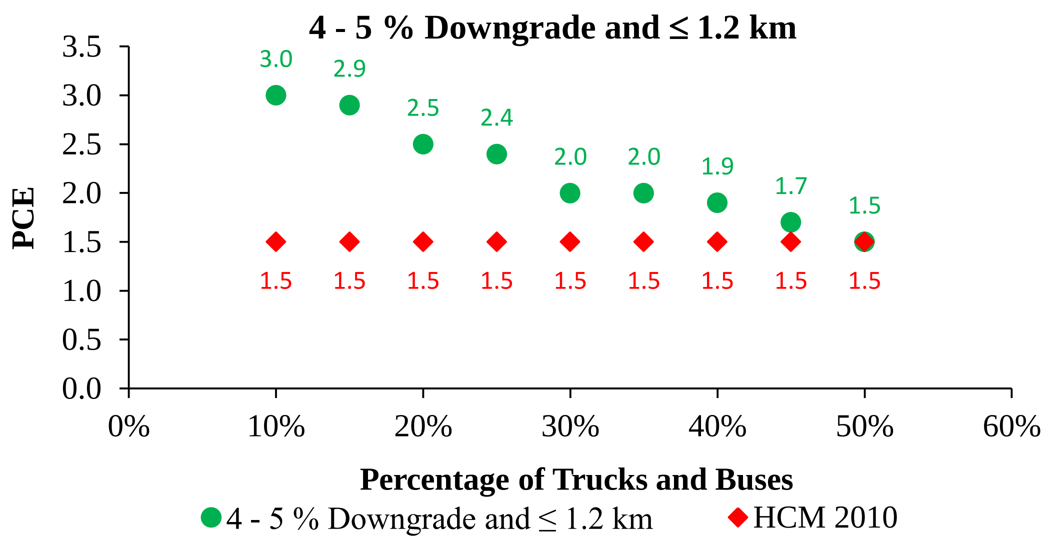


Figure 4.10: PCE Variability by truck proportion, ≤ 1.2 km grade length and 4-5 % downgrade

4.2.2 Variability of Grade Length by PCE

The grade length in HCM 2010 includes 1.5 mi (2.4 km) up to 4 % upgrade and 1mi (1.6 km) up to 6 % upgrade and also 4 mi (6.4 km) up to 6 % downgrade. However, for Addis Ababa – Adama expressway includes 1.6 km for ≤ 2 %, > 3 – 4 and > 4 – 5, 0.8 km for > 2 – 3 % upgrades, and ≤ 0.8 km for < 4 % and ≤ 1.2 km for 4 - 5 % downgrade.

From Figure 4.11 up to Figure 4.22 observed that the PCE increase as the length of grade increases and this way also exist in the PCEs that was provided in HCM 2010. It is observed that for steeper grades the PCE values change more significantly and the proportion of trucks and buses increases the PCE variability decreases non-linearly, a higher PCE value for the 10 % proportion of trucks and buses as matched to 20 % proportion of trucks and buses.

Figure 4.11 shows variability PCE by grade length for ≤ 2% upgrade and 10 % trucks and buses by using Flow Density method.

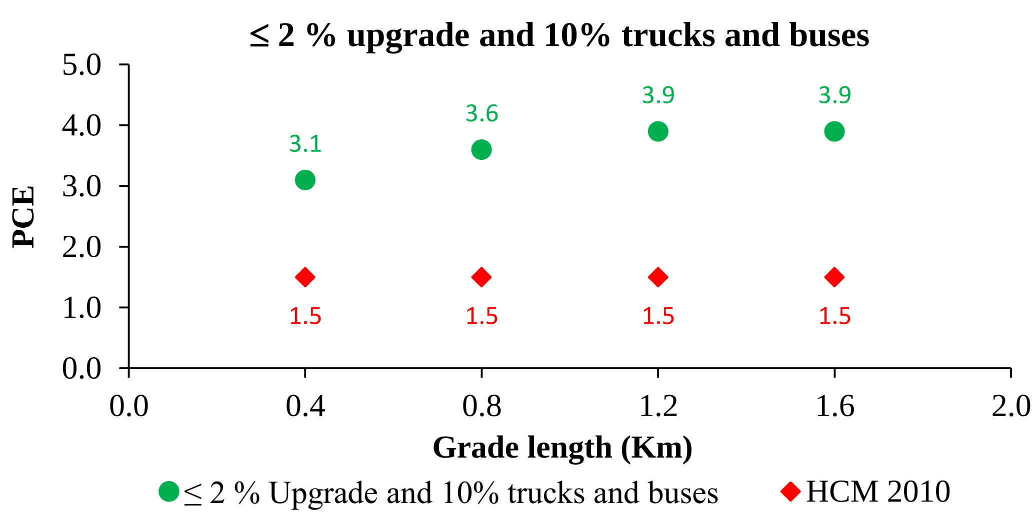


Figure 4.11: PCE Variability by grade length, ≤ 2% upgrade and 10 % trucks and buses

Figure 4.12 shows variability PCE by grade length for ≤ 2% upgrade and 20 % trucks and buses by using Flow Density method.

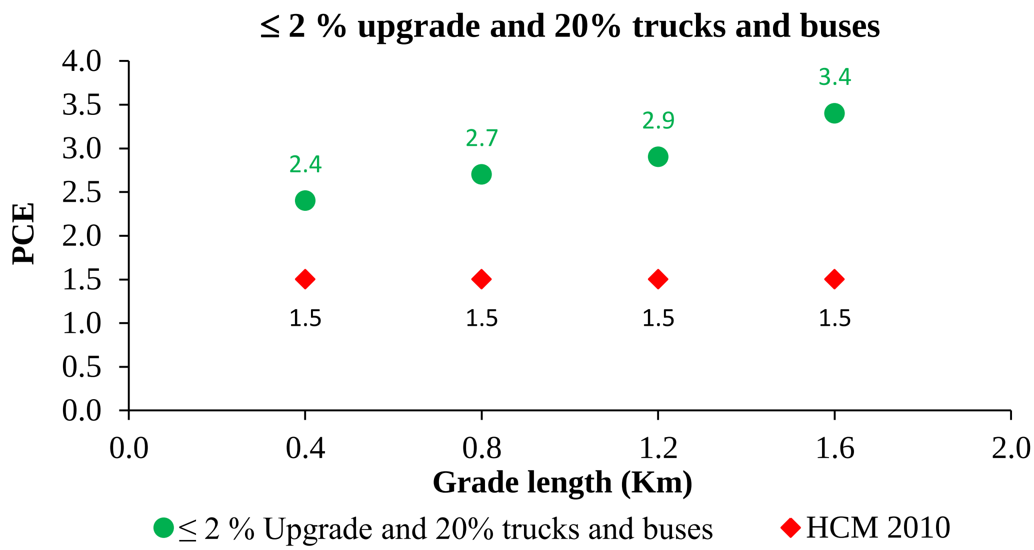


Figure 4.12: PCE Variability by grade length, ≤ 2% upgrade and 20 % trucks and buses

Figure 4.13 shows variability PCE by grade length for ≤ 2% upgrade and 35 % trucks and buses by using Flow Density method.

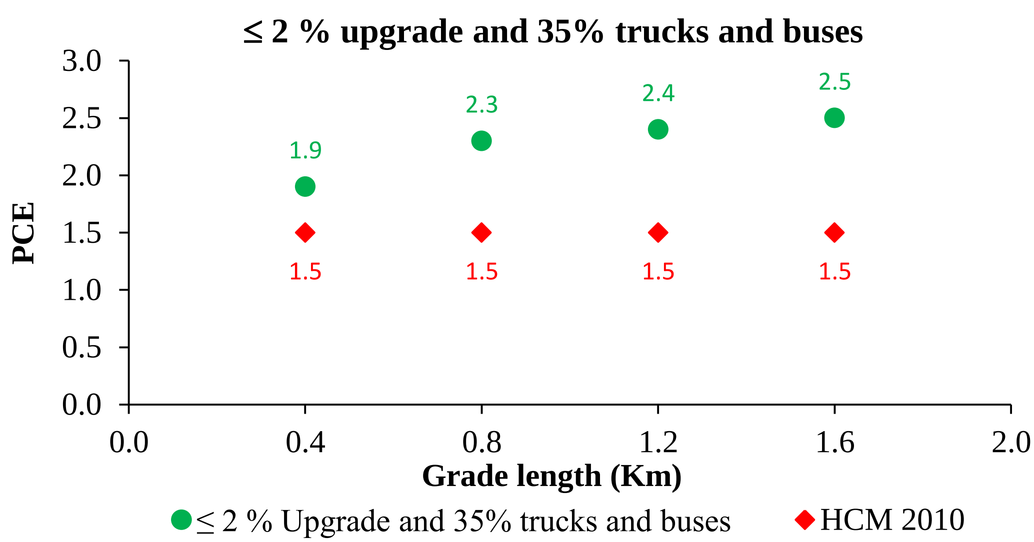


Figure 4.13: PCE Variability by grade length, ≤ 2% upgrade and 35 % trucks and buses

Figure 4.14 shows variability PCE by grade length for ≤ 2% upgrade and 50 % trucks and buses by using Flow Density method.

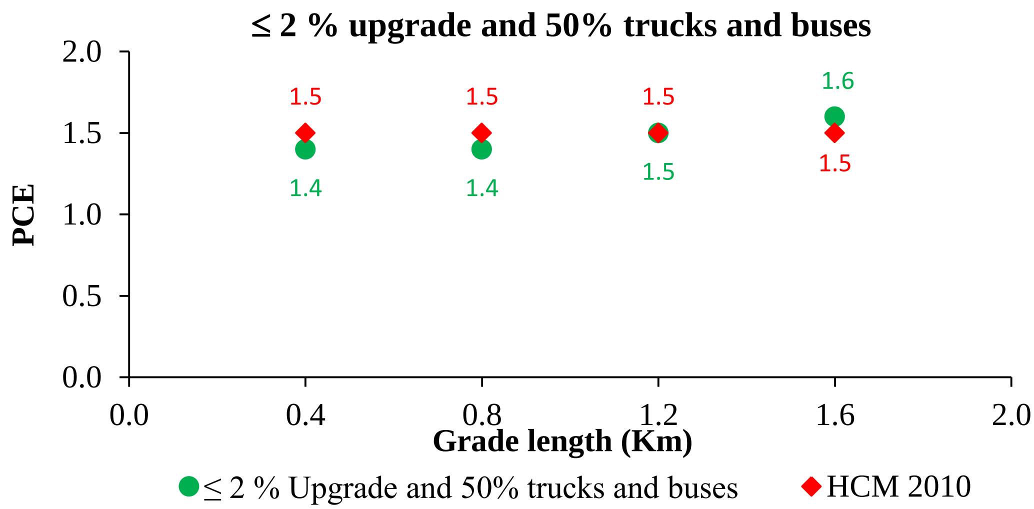


Figure 4.14: PCE Variability by grade length, ≤ 2% upgrade and 50 % trucks and buses

Figure 4.15 shows variability PCE by grade length for > 3 – 4 % upgrade and 10% trucks and buses by using Flow Density method.

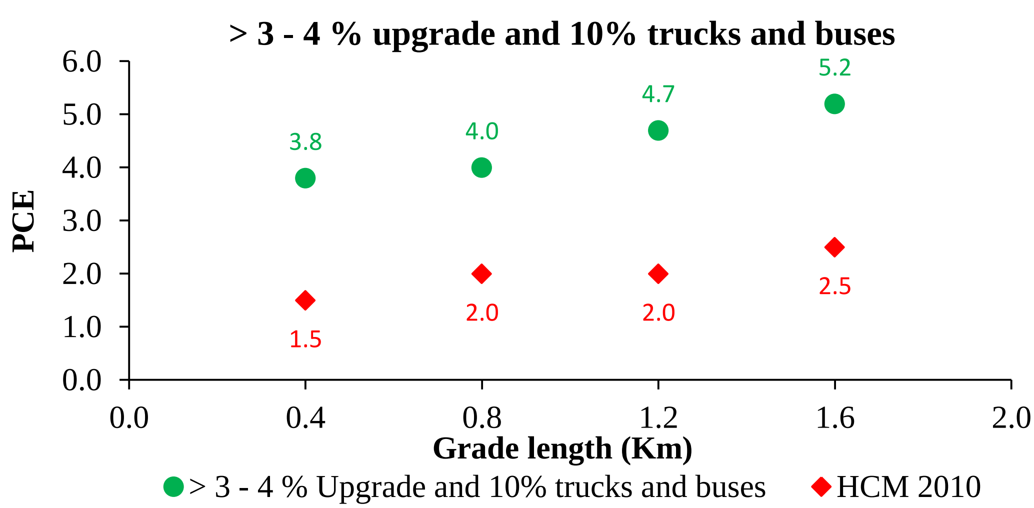


Figure 4.15: PCE Variability by grade length, for > 3 - 4 % upgrade and 10% trucks and buses

Figure 4.16 shows variability PCE by grade length for > 3 - 4 % upgrade and 20% trucks and buses by using Flow Density method.

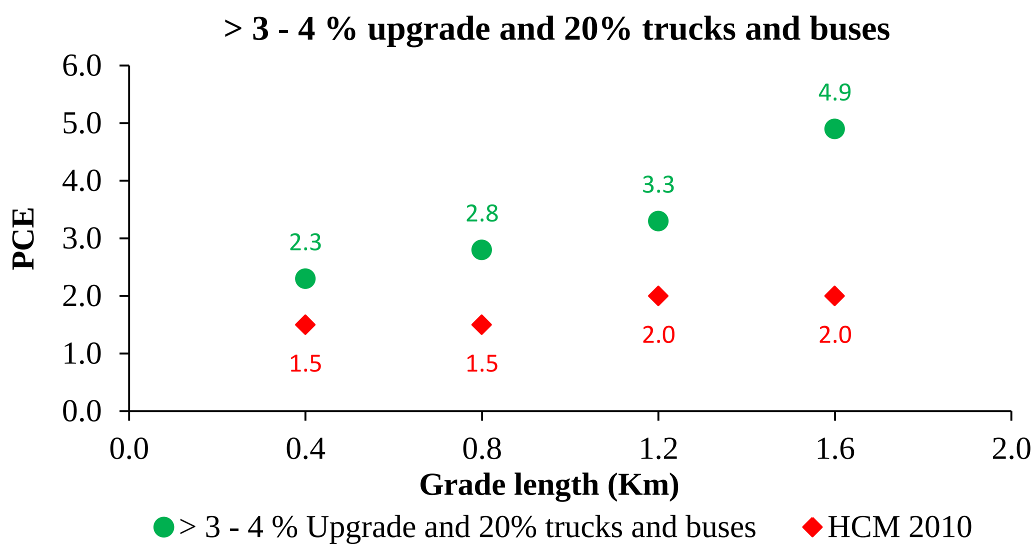


Figure 4.16: PCE Variability by grade length, > 3 – 4 % upgrade and 20% trucks and buses

Figure 4.17 shows variability PCE by grade length for > 3 - 4% upgrade and 35% trucks and buses by using Flow Density method.

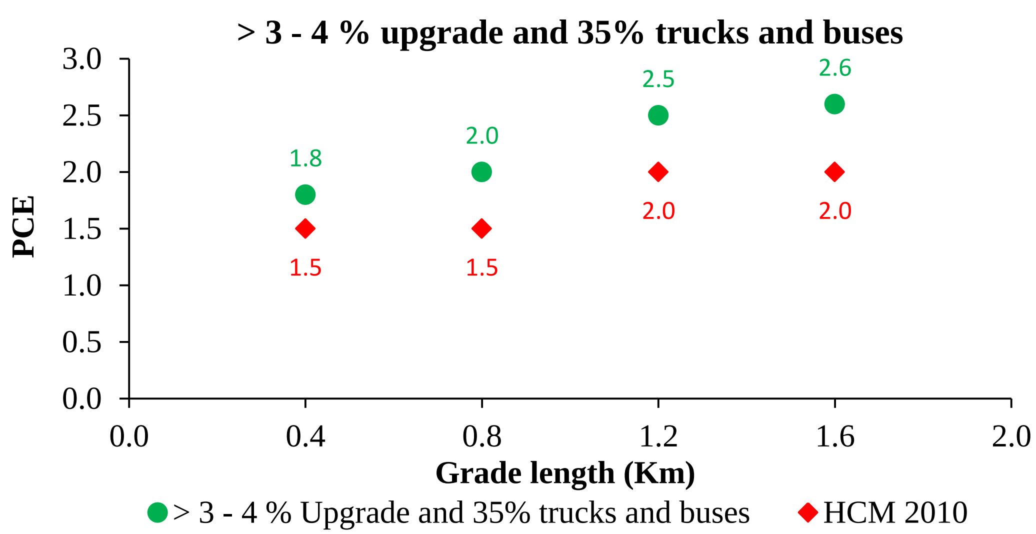


Figure 4.17: PCE Variability by grade length, for > 3 - 4 % upgrade and 35% trucks and buses

Figure 4.18 shows variability PCE by grade length for > 3 - 4% upgrade and 50% trucks and buses by using Flow Density method.

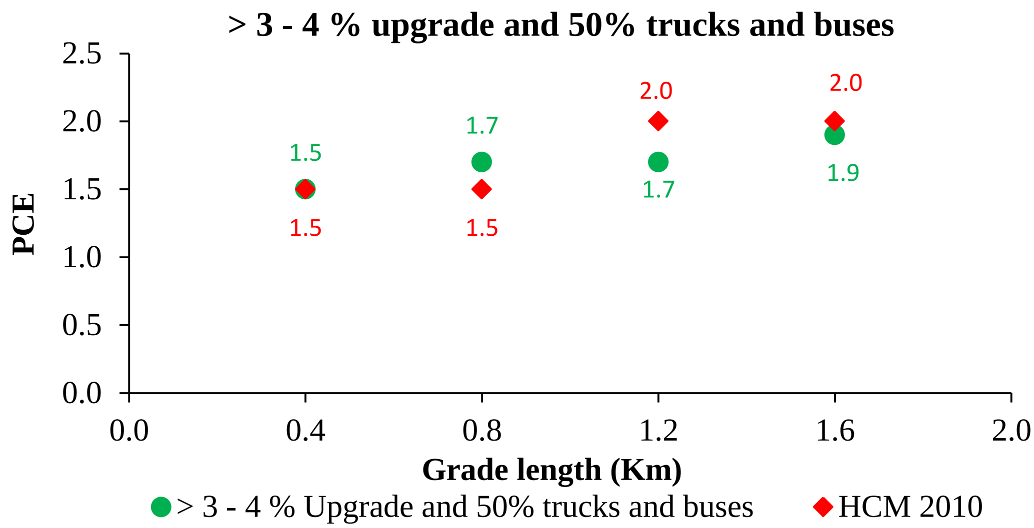


Figure 4.18: PCE Variability by grade length, > 3 – 4% upgrade and 50 % trucks and buses

Figure 4.19 shows variability PCE by grade length for > 4 – 5 % upgrade and 10 % trucks and buses by using Flow Density method.

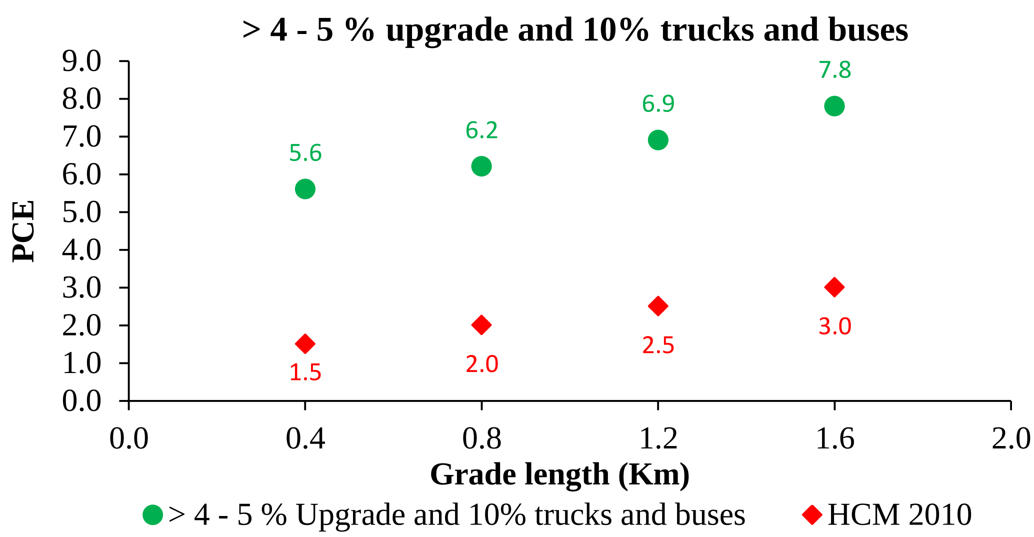


Figure 4.19: PCE Variability by grade length, for > 4 - 5 % upgrade and 10% trucks and buses

Figure 4.20 shows variability PCE by grade length for > 4 – 5 % upgrade and 20 % trucks and buses by using Flow Density method.

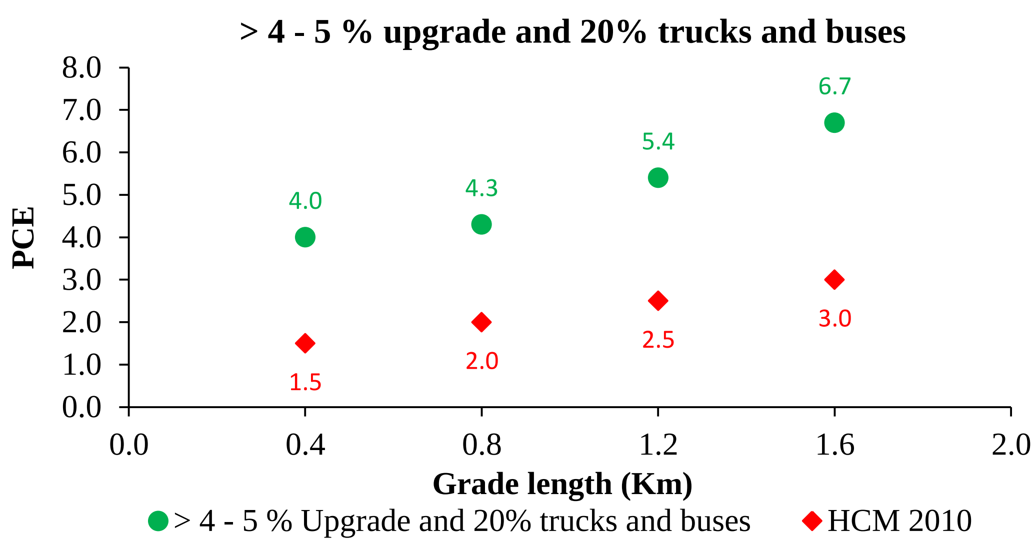


Figure 4.20: PCE Variability by grade length, > 4 – 5 % upgrade and 20 % trucks and buses

Figure 4.21 shows variability PCE by grade length for > 4 – 5 % upgrade and 35 % trucks and buses by using Flow Density method.

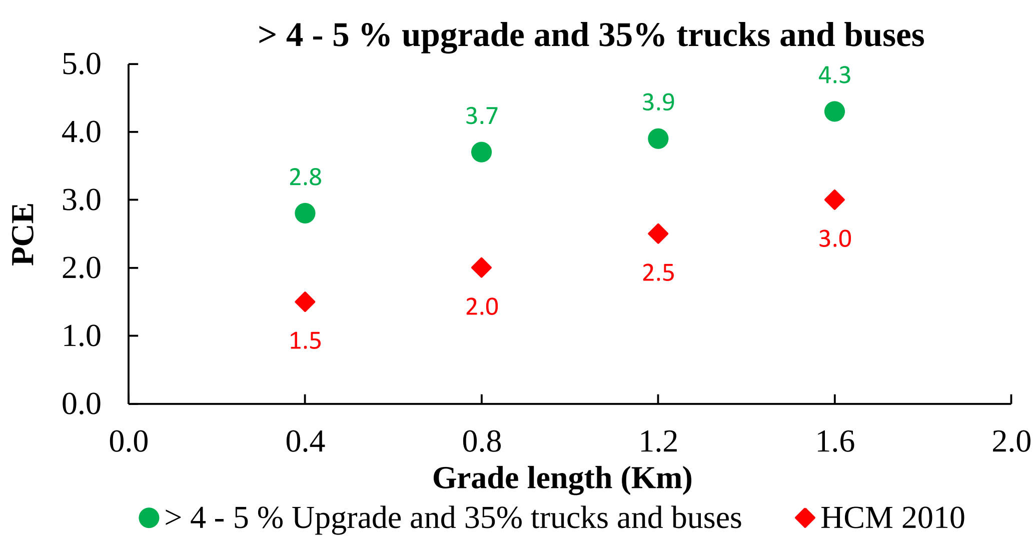


Figure 4.21: PCE Variability by grade length, for > 4 - 5% upgrade and 35 % trucks and buses

Figure 4.22 shows variability PCE by grade length for > 4 – 5 % upgrade and 50 % trucks and buses by using Flow Density method.

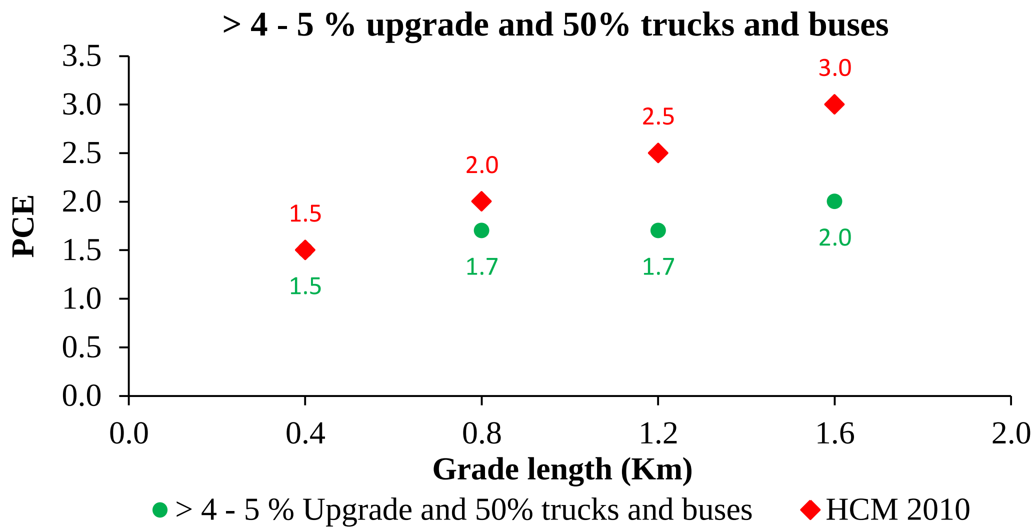


Figure 4.22: PCE Variability by grade length, > 4 – 5 % upgrade and 50 % trucks and buses

4.2.3 Variability of Percentages of Grade by PCE

According to HCM 2010, the effect of heavy vehicles on traffic flow depends on terrain and grade conditions as well as traffic compositions.

In HCM 2010 trucks and buses the passenger car equivalents for specific upgrade considers up to six percent. Due to the availability of upgrades in this study considers up to five percent.

From Figure 4.23 up to Figure 4.31 observed that the PCE increases as the percentage of grade increased non-linearly and shows the variability of the PCE over percent grades ranging from one to five percent. And also from Figure 4.23 up to Figure 4.31 observed that for a highest percentage of grade the PCE values varies more significantly.

Figure 4.23 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 10 % trucks and buses by using Flow Density method.

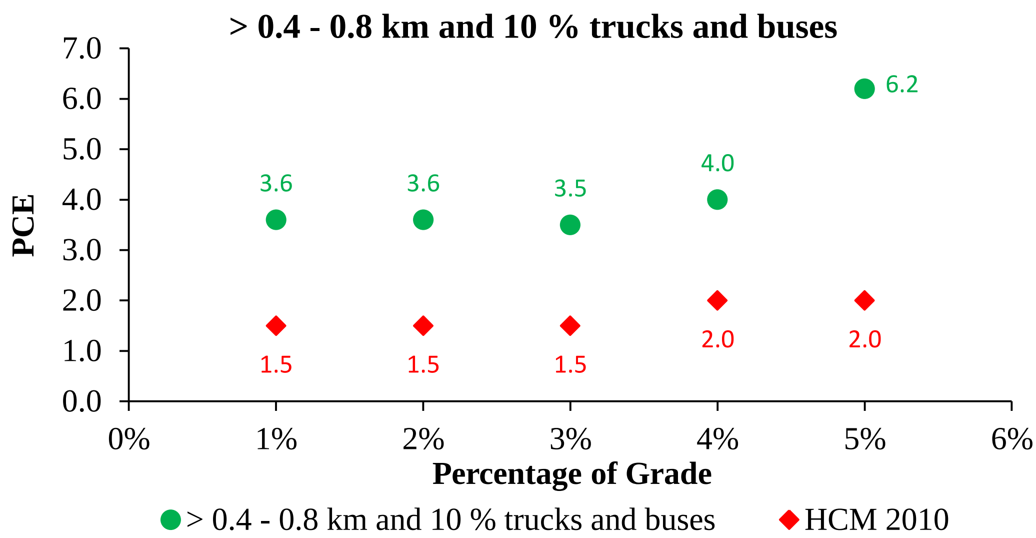


Figure 4.23: PCE Variability by percentage grade, > 0.4 – 0.8 km and 10 % trucks and buses

Figure 4.24 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 15 % trucks and buses by using Flow Density method.

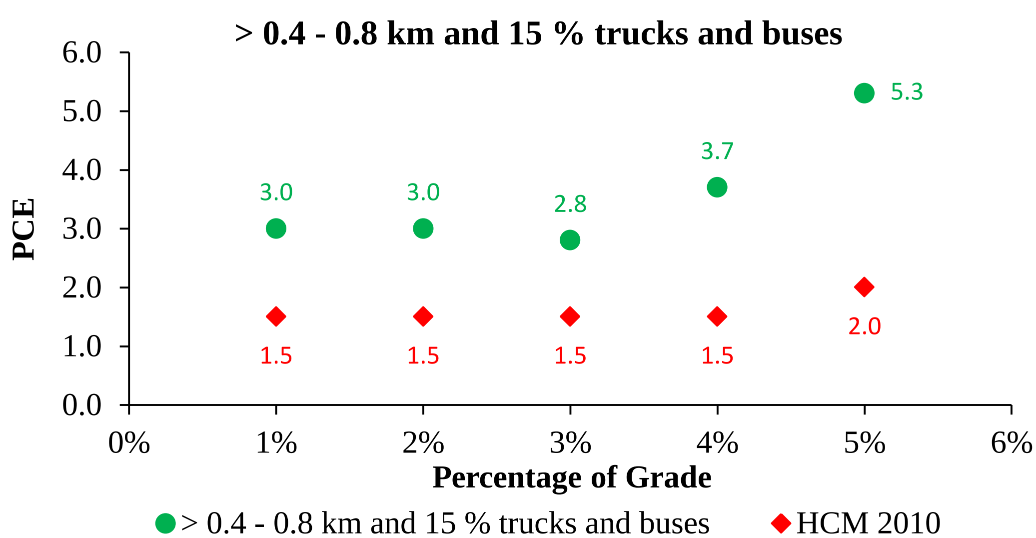


Figure 4.24: PCE Variability by percentage grade, > 0.4 – 0.8 km and 15 % trucks and buses

Figure 4.25 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 20% trucks and buses by using Flow Density method.

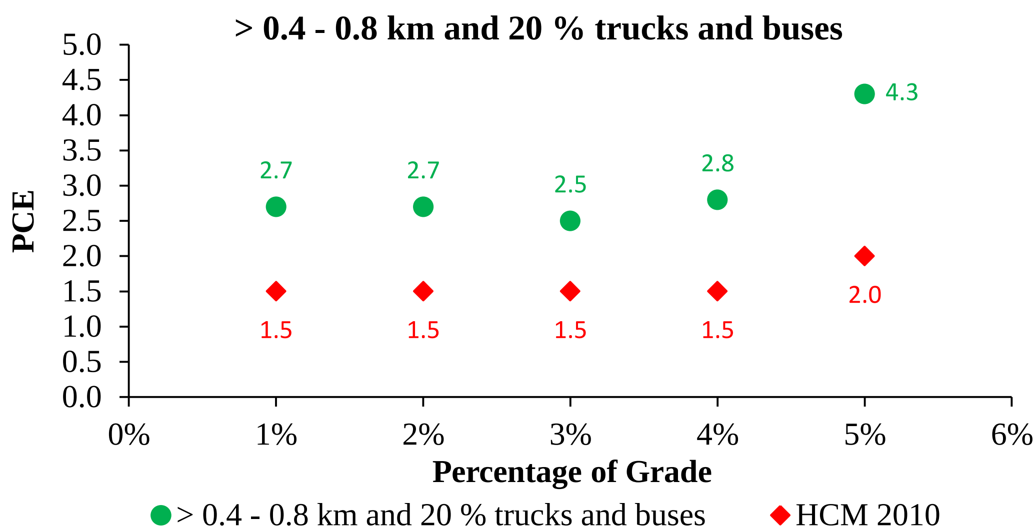


Figure 4.25: PCE Variability by percentage grade, > 0.4 – 0.8 km and 20% trucks and buses

Figure 4.26 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 25 % trucks and buses by using Flow Density method.

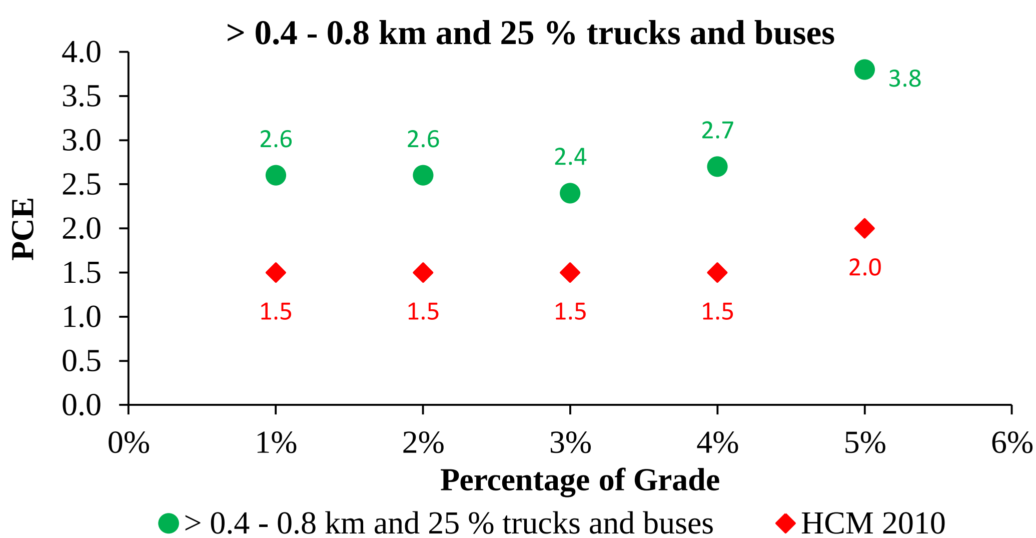


Figure 4.26: PCE Variability by percentage grade, > 0.4 – 0.8 km and 25 % trucks and buses

Figure 4.27 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 30 % trucks and buses by using Flow Density method.

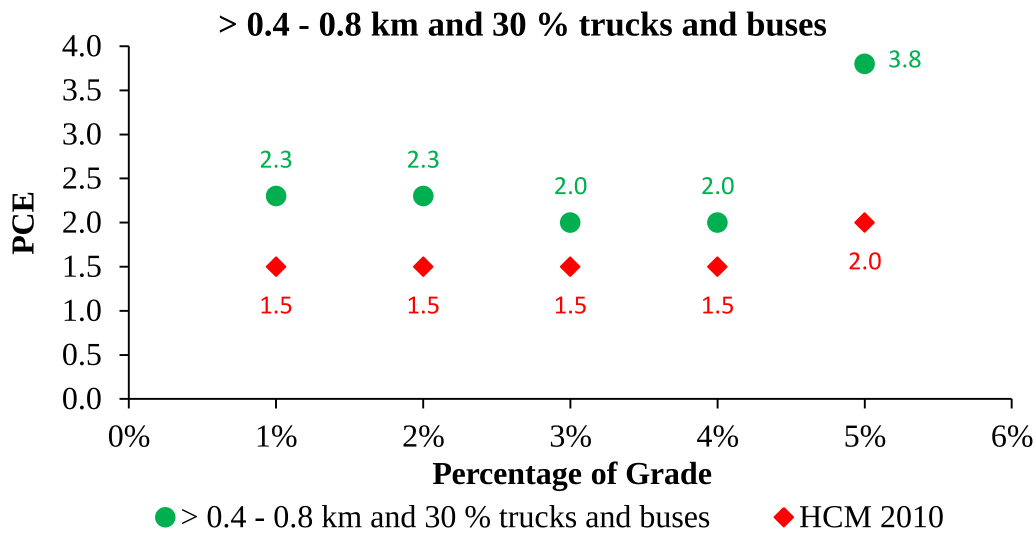


Figure 4.27: PCE Variability by percentage grade, > 0.4 – 0.8 km and 30 % trucks and buses

Figure 4.28 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 35 % trucks and buses by using Flow Density method.

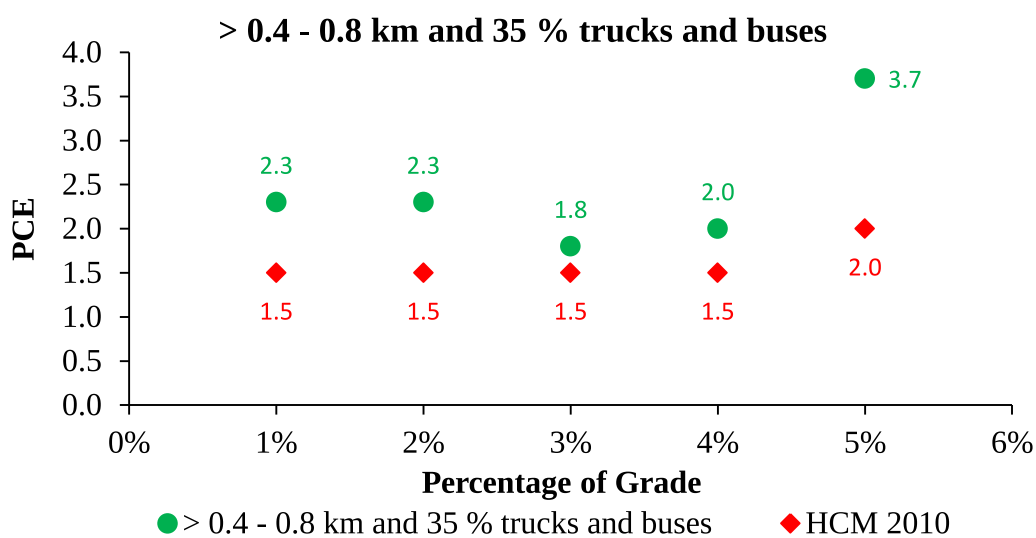


Figure 4.28: PCE Variability by percentage grade, > 0.4 – 0.8 km and 20 % trucks and buses

Figure 4.29 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 40 % trucks and buses by using Flow Density method.

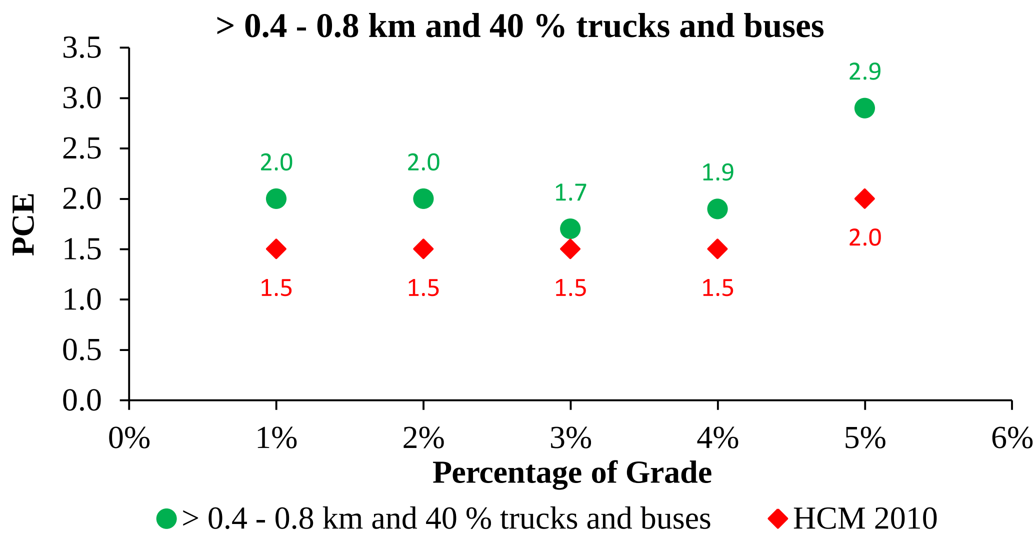


Figure 4.29: PCE Variability by percentage grade, > 0.4 – 0.8 km and 40 % trucks and buses

Figure 4.30 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 45 % trucks and buses by using Flow Density method.

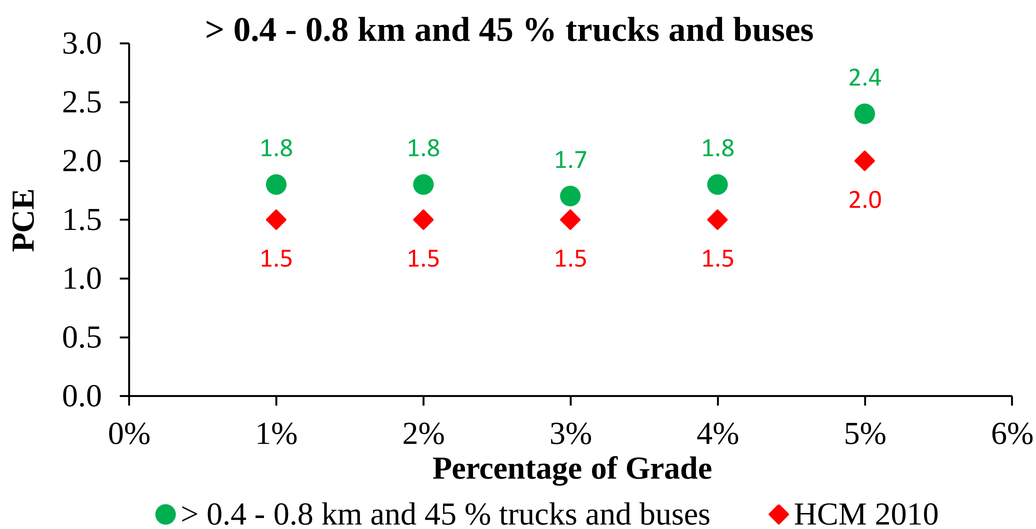


Figure 4.30: PCE Variability by percentage grade, > 0.4 – 0.8 km and 45 % trucks and buses

Figure 4.31 shows variability PCE by percentage of grade for > 0.4 – 0.8 km and 50 % trucks and buses by using Flow Density method.

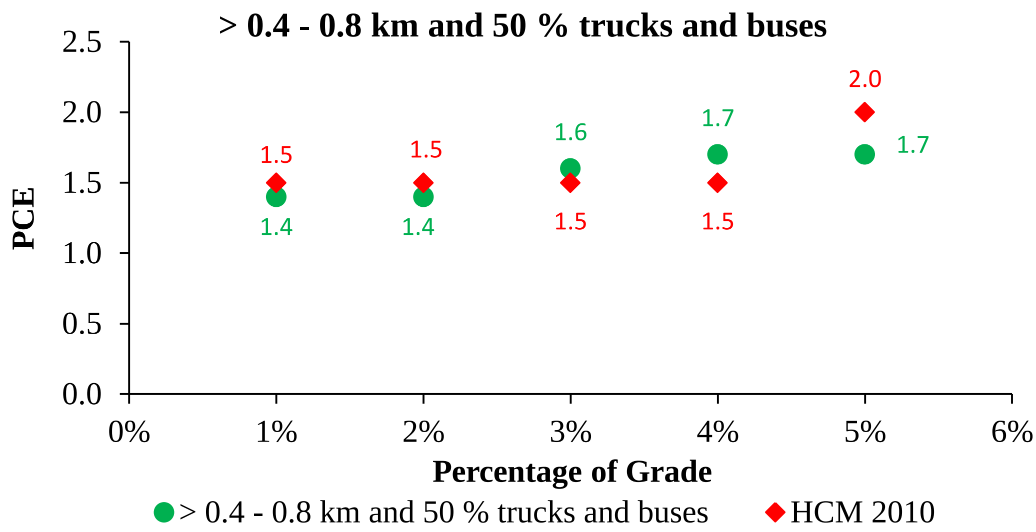


Figure 4.31: PCE Variability by percentage grade, > 0.4 – 0.8 km and 50 % trucks and buses

From Table 4.3 and 4.4 shows that there is a difference between the executed Passenger Car Equivalent and Passenger Car Equivalent on HCM 2010. Thus, according to the data and analysis in Appendix F, the basic freeway segment of a six-lane in Addis Ababa – Adama Expressway is expected to operate at LOS A during the worst 15 minutes of the peak hour. It is important to note that the operation, although at LOS A. A result from the calculated LOS with the executed PCE value and HCM 2010 provided PCE value shows the LOS A but there is a difference in demand volume as well as density of the traffic stream. So the difference shows the executed PCE gives a better decision in the future according to the local condition while demand volume increases but on the time being the demand volume is small so may not be seen a significant difference. Finally, using the executed Passenger Car Equivalents shows better assumption than Passenger Car Equivalents on HCM 2010.

4.2.4 The Proposed PCEs for Trucks and Buses on Upgrades and Downgrades

Table 4.1: Executed PCEs for Trucks and Buses (E_T) on Specific Upgrades

Upgrade (%)	Length (km)	Proportion of Trucks and Buses								
		10%	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
≤ 2	0.0 - 0.4	3.1	2.8	2.4	2.0	1.9	1.9	1.9	1.7	1.4
	> 0.4 - 0.8	3.6	3.0	2.7	2.6	2.3	2.3	2.0	1.8	1.4
	> 0.8 - 1.2	3.9	3.4	2.9	2.6	2.5	2.4	2.0	1.9	1.5
	> 1.2 - 1.6	3.9	3.5	3.4	2.8	2.6	2.5	2.4	2.1	1.6
> 2-3	0.0 - 0.4	2.8	2.5	2.3	2.1	1.9	1.6	1.6	1.6	1.4
	> 0.4 - 0.8	3.5	2.8	2.5	2.4	2.0	1.8	1.7	1.7	1.6
> 3-4	0.0 - 0.4	3.8	3.1	2.3	2.2	1.9	1.8	1.8	1.7	1.5
	> 0.4 - 0.8	4.0	3.7	2.8	2.7	2.0	2.0	1.9	1.8	1.7
	> 0.8 - 1.2	4.7	3.8	3.3	3.3	2.7	2.5	2.3	2.3	1.7
	> 1.2 - 1.6	5.2	5.1	4.9	3.9	2.7	2.6	2.6	2.0	1.9
> 4-5	0.0 - 0.4	5.6	5.2	4.0	3.7	3.5	2.8	2.6	2.1	1.5
	> 0.4 - 0.8	6.2	5.3	4.3	3.8	3.8	3.7	2.9	2.4	1.7
	> 0.8 - 1.2	6.9	6.5	5.4	5.0	4.5	3.9	3.5	2.6	1.7
	> 1.2 - 1.6	7.8	7.1	6.7	5.5	5.3	4.3	3.5	2.7	2.0

Table 4.2: Executed PCEs for Trucks and Buses (E_T) on Specific Downgrades

Downgrade (%)	Length (km)	Proportion of Trucks and Buses								
		10%	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
< 4	≤ 0.8	2.9	2.8	2.4	2.3	2.0	1.9	1.8	1.6	1.5
4 - 5	≤ 1.2	3.0	2.9	2.5	2.4	2.0	2.0	1.9	1.7	1.5

The proposed upgrade PCE values compared with the PCE values in HCM 2010 tabulated and shown on Table 4.3.

Table 4.3: Compared Executed PCEs for Trucks and Buses (E_T) on Specific Upgrades

Upgrade (%)	Length (km)	Proportion of Trucks and Buses																	
		10%		15%		20%		25%		30%		35%		40%		45%		50%	
		Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE
≤ 2	0.0 - 0.4	3.1	1.5	2.8	1.5	2.4	1.5	2.0	1.5	1.9	1.5	1.9	1.5	1.9	1.5	1.7	1.5	1.4	1.5
	> 0.4 - 0.8	3.6	1.5	3.0	1.5	2.7	1.5	2.6	1.5	2.3	1.5	2.3	1.5	2.0	1.5	1.8	1.5	1.4	1.5
	> 0.8 - 1.2	3.9	1.5	3.4	1.5	2.9	1.5	2.6	1.5	2.5	1.5	2.4	1.5	2.0	1.5	1.9	1.5	1.5	1.5
	> 1.2 - 1.6	3.9	1.5	3.5	1.5	3.4	1.5	2.8	1.5	2.6	1.5	2.5	1.5	2.4	1.5	2.1	1.5	1.6	1.5
> 2-3	0.0 - 0.4	2.8	1.5	2.5	1.5	2.3	1.5	2.1	1.5	1.9	1.5	1.6	1.5	1.6	1.5	1.6	1.5	1.4	1.5
	> 0.4 - 0.8	3.5	1.5	2.8	1.5	2.5	1.5	2.4	1.5	2.0	1.5	1.8	1.5	1.7	1.5	1.7	1.5	1.6	1.5
> 3-4	0.0 - 0.4	3.8	1.5	3.1	1.5	2.3	1.5	2.2	1.5	1.9	1.5	1.8	1.5	1.8	1.5	1.7	1.5	1.5	1.5
	> 0.4 - 0.8	4.0	2.0	3.7	1.5	2.8	1.5	2.7	1.5	2.0	1.5	2.0	1.5	1.9	1.5	1.8	1.5	1.7	1.5
	> 0.8 - 1.2	4.7	2.0	3.8	2.0	3.3	2.0	3.3	2.0	2.7	2.0	2.5	2.0	2.3	2.0	2.3	2.0	1.7	2.0
	> 1.2 - 1.6	5.2	2.5	5.1	2.0	4.9	2.0	3.9	2.0	2.7	2.0	2.6	2.0	2.6	2.0	2.0	2.0	1.9	2.0
> 4-5	0.0 - 0.4	5.6	1.5	5.2	1.5	4.0	1.5	3.7	1.5	3.5	1.5	2.8	1.5	2.6	1.5	2.1	1.5	1.5	1.5
	> 0.4 - 0.8	6.2	2.0	5.3	2.0	4.3	2.0	3.8	2.0	3.8	2.0	3.7	2.0	2.9	2.0	2.4	2.0	1.7	2.0
	> 0.8 - 1.2	6.9	2.5	6.5	2.5	5.4	2.5	5.0	2.5	4.5	2.5	3.9	2.5	3.5	2.5	2.6	2.5	1.7	2.5
	> 1.2 - 1.6	7.8	3.0	7.1	3.0	6.7	3.0	5.5	3.0	5.3	3.0	4.3	3.0	3.5	3.0	2.7	3.0	2.0	3.0

The proposed downgrade PCE values compared with the PCE values in HCM 2010 tabulated and shown on Table 4.4

Table 4.4: Compared Executed PCEs for Trucks and Buses (E_T) on Specific Downgrades

Downgrade (%)	Length (km)	Proportion of Trucks and Buses																	
		10%		15%		20%		25%		30%		35%		40%		45%		50%	
		Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE	Executed PCE	HCM 2010 PCE
< 4	≤ 0.8	2.9	1.5	2.8	1.5	2.4	1.5	2.3	1.5	2.0	1.5	1.9	1.5	1.8	1.5	1.6	1.5	1.5	1.5
4 - 5	≤ 1.2	3.0	1.5	2.9	1.5	2.5	1.5	2.4	1.5	2.0	1.5	2.0	1.5	1.9	1.5	1.7	1.5	1.5	1.5

4.2.5 Passenger Car Equivalents for General Terrain Segments

According to HCM 2010 General terrain refers to extended lengths of freeway containing a number of upgrades and downgrades where no one grade is long enough or steep enough to have a significant impact on the operation of the overall segment.

There are three types of general terrain:

- ✓ Level terrain: Any combination of alignments permits heavy vehicles to maintain approximately the same speed as passenger cars. Generally includes short grades of no more than 2%.
- ✓ Rolling terrain: Any combination of alignment that causes heavy vehicles to reduce speed substantially below passenger cars but does not cause them to operate at their crawl speeds for the given terrain for any significant length of time or at frequent intervals.
- ✓ Mountainous terrain: Any combination alignment that causes heavy vehicles to operate at crawl speed for significant distances or at frequent intervals.

So, from this study a proposed Passenger Car Equivalents for Trucks and Buses in general terrain tabulated and shown on Table 4.5 and Table 4.6.

Table 4.5: Executed PCEs for Trucks and Buses (E_T) in General Terrain

Vehicle	**PCE by Type of Terrain**		
	Level	**Rolling**	**Mountainous**
Trucks and buses, E_T	2.5	3.0	-

Table 4.6: Compared Executed PCEs for Trucks and Buses (E_T) in General Terrain

Vehicle	**PCE by Type of Terrain**					
	Level		**Rolling**		**Mountainous**	
	Executed	**HCM 2010**	**Executed**	**HCM 2010**	**Executed**	**HCM 2010**
Trucks and buses, E_T	2.5	1.5	3.0	2.5	-	4.5

Chapter 5. Conclusions and Recommendations

5.1 Conclusions

The basic objective of this research is to evaluate Passenger Car Equivalents for trucks and buses for basic freeway segments on Addis Ababa – Adama Expressway by considering trucks proportion, grade percentages, and length of grades using Equal Flow Density method.

The study illustrates that:

- ✓ The Passenger Car Equivalents values decrease non-linearly as the truck proportion increases in less than or equal to two percent (≤ 2%), greater than two up to three percent (> 2 – 3%), greater than three up to four percent (> 3 – 4%), and greater than four up to five percent (> 4 - 5) on upgrades, and less than four percent (< 4%) and from four up to five percent (4 – 5%) on downgrade. Most of PCE variability occurs in low proportion of trucks and buses.

- ✓ For trucks and buses proportions near to 50%, the Passenger Car Equivalents values show insignificant variability. The major variation observed in a lower trucks and buses proportion. For trucks and buses proportions from 10 % up to 50 %, the value of PCE varies in between 1.4 up to 7.8 for upgrade of up to 5 % which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0.

- ✓ The Passenger Car Equivalents increases non-linearly as the length of grade increases in both upgrades and downgrades. For trucks and buses proportions of 10 %, the value of PCE varies with the length of grade in between 5.6 up to 7.8 for 5 % upgrade which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0.

- ✓ The Passenger Car Equivalents increases non-linearly as the percent grade increases in both upgrades and downgrades. For trucks and buses proportions of 10 %, the value of PCE varies with the percent grade in between 2.8 up to 7.8 for upgrade of up to 5 % which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0.

- ✓ From this study grade length has significant effect on Passenger Car Equivalents in steeper upgrades than gentle upgrades, and the percentage of grade has significant effect on Passenger Car Equivalents in higher grades than lower grades, and also the percentage of trucks has significant effect on Passenger Car Equivalents in lower proportion of trucks and buses than higher proportion of trucks and buses.

- ✓ For analysis using the executed Passenger Car Equivalents shows a better assumption than Passenger Car Equivalents on HCM 2010. Due to the reason that the executed PCE value gives according to the local condition without adjustment of HCM 2010 PCE values.

5.2 Recommendations

- ✓ The result of this study for upgrade up to 5 % with grade length up to 1.6 km and proportion of trucks and buses from 10 % up to 50 % shown in Table 4.1. And downgrade up to 5 % with grade length up to 1.2 km and proportion of trucks and buses from 10 % up to 50 % shown in Table 4.2. So, Table 4.1 and 4.2 are the proposed recommended PCE values by using Equal Flow Density method.

- ✓ The Passenger Car Equivalent found from this study have significantly different from the Passenger Car Equivalent in Highway Capacity Manual 2010, so based on this the proposed Passenger Car Equivalent is an important for Ethiopian traffic Engineers who plan, design, operate and maintain freeways corresponding to the local traffic conditions.

<u>Recommendations for future study</u>

- ➢ This study was done in Level of Service A, but repeats this study when the Level of Service reaches C or D and compare with that of the proposed Passenger Car Equivalents.

- ➢ The Level of Service may not be acceptable for similar freeways in every country, so it is better to study the types of Level of Services according to the local traffic conditions.

- ➢ Determine the Passenger Car Equivalents with the method that consider the performance of vehicles and compare with the proposed values.

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Appendix A

Profile Data for Addis Ababa – Adama Expressway

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
1	K2 + 500	K2 + 920	**-1.60**	**420**	2151.077	2146.361	**Basic Freeway Segment**	
2	K2 + 920	K3 + 520	**2.50**	**600**	2146.361	2160.076		
3	K3 + 520	K4 + 020	**3.70**	**500**	2160.076	2178.254		> 3 - 4 % of Grade
4	K4 + 020	K4 + 520	**3.99**	**500**	2178.254	2197.612		
5	K4 + 520	K4 + 920	**2.55**	**400**	2197.612	2208.960		
6	K4 + 920	K5 + 610	**4.60**	**690**	2208.96	2230.179		
7	K5 + 610	K6 + 250	**-4.30**	**640**	2230.179	2212.810		
8	K6 + 250	K6 + 650	**-2.10**	**400**	2212.810	2202.634		
9	K6 + 650	K7 + 050	**-5.00**	**400**	2202.634	2184.091		
10	K7 + 050	K7 + 450	**-3.60**	**400**	2184.091	2170.512		
11	K7 + 450	K7 + 880	**-0.50**	**430**	2170.512	2166.874		
12	K7 + 880	K8 + 320	**-2.70**	**440**	2166.874	2155.600		
13	K8 + 320	K8 + 720	**-3.10**	**400**	2155.600	2143.680		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
14	K8 + 720	K9 + 260	**-1.90**	**540**	2143.680	2131.498	**Basic Freeway Segment**	
15	K9 + 260	K10 + 460	**-5.00**	**1200**	2131.498	2073.905		> 4 - 5 % of Grade
16	K10 + 460	K11 + 100	**-2.40**	**640**	2073.905	2059.382		
17	K11 + 100	K11 + 740	**0.50**	**640**	2059.382	2059.357		
18	K11 + 740	K12 + 230	**-1.60**	**490**	2059.357	2052.570		
19	K12 + 230	K12 + 630	**-2.70**	**400**	2052.570	2043.742		
20	K12 + 630	K13 + 030	**1.80**	**400**	2043.742	2049.340		
21	K13 + 030	K13 + 700	**0.90**	**670**	2049.340	2053.901		
22	K13 + 700	K14 + 360	**-2.50**	**660**	2053.901	2037.818		
23	K14 + 360	K15 + 560	**-5.00**	**1200**	2037.818	1979.740		
24	K15 + 560	K16 + 180	**-3.00**	**620**	1979.740	1961.171		
25	K16 + 180	K16 + 870	**-0.50**	**690**	1961.171	1956.960	At K16 + 500 (Debre Zeit North - Interchange Start Point) & At K17 + 600 (Debre Zeit North - Interchange End Point)	
26	K16 + 870	K17 + 360	**-0.30**	**490**	1956.960	1955.386		
27	K17 + 360	K17 + 810	**-0.60**	**450**	1955.386	1951.988		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
28	K17 + 810	K18 + 260	**-2.20**	**450**	1951.988	1943.502	**Basic Freeway Segment**	
29	K18 + 260	K18 + 720	**-0.30**	**460**	1943.502	1939.703		
30	K18 + 720	K19 + 140	**-3.20**	**420**	1939.703	1927.810		
31	K19 + 140	K19 + 690	**-4.00**	**550**	1927.810	1907.551		
32	K19 + 690	K20 + 300	**-0.30**	**610**	1907.551	1904.075		
33	K20 + 300	K20 + 800	**-0.76**	**500**	1904.075	1900.771		
34	K20 + 800	K21 + 290	**0.30**	**490**	1900.771	1901.369		
35	K21 + 290	K22 + 000	**-0.88**	**710**	1901.369	1895.689		
36	K22 + 000	K22 + 680	**-0.55**	**680**	1895.689	1892.088		
37	K22 + 680	K23 + 470	**0.00**	**790**	1892.088	1892.031		
38	K23 + 470	K23 + 960	**0.40**	**490**	1892.031	1892.937		
39	K23 + 960	K24 + 800	**-1.50**	**840**	1892.937	1881.969		
40	K24 + 800	K25 + 340	**0.30**	**540**	1881.969	1882.482		
41	K25 + 340	K25 + 810	**-0.80**	**470**	1882.482	1879.362		
42	K25 + 810	K27 + 660	**-0.06**	**1850**	1879.362	1877.744		≤ 2 % of Grade

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
43	K27 + 660	K28 + 310	**-0.50**	**650**	1877.744	1875.408	**Basic Freeway Segment**	
44	K28 + 310	K28 + 700	**0.85**	**400**	1875.408	1877.337	At K28 + 400 (Debre Zeit Service Station Start Point) & At K29 + 500 (Debre Zeit Service Station End Point)	
45	K28 + 700	K29 + 210	**-1.00**	**500**	1877.337	1873.591		
46	K29 + 210	K30 + 100	**0.34**	**890**	1873.591	1875.649		
47	K30 + 100	K30 + 580	**-1.10**	**480**	1875.649	1872.303	**Basic Freeway Segment**	
48	K30 + 580	K31 + 080	**0.57**	**500**	1872.303	1873.232		
49	K31 + 080	K31 + 520	**-0.65**	**440**	1873.232	1871.628		
50	K31 + 520	K32 + 120	**1.70**	**600**	1871.628	1880.510		
51	K32 + 120	K32 + 790	**0.30**	**670**	1880.510	1882.118		
52	K32 + 790	K33 + 490	**-1.52**	**700**	1882.118	1872.551	At K33 + 300 (Debre Zeit South - Interchange Start Point) & At K34 + 500 (Debre Zeit South - Interchange End Point)	
53	K33 + 490	K34 + 190	**-0.67**	**700**	1872.551	1867.664		
54	K34 + 190	K34 + 790	**-0.55**	**600**	1867.664	1865.006		
55	K34 + 790	K35 + 610	**1.00**	**820**	1865.006	1871.680	**Basic Freeway Segment**	
56	K35 + 610	K36 + 210	**-0.90**	**600**	1871.680	1867.005		
57	K36 + 210	K36 + 710	**-1.10**	**500**	1867.005	1861.463		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
58	K36 + 710	K37 + 210	**-1.35**	**500**	1861.463	1855.080	**Basic Freeway Segment**	
59	K37 + 210	K37 + 610	**-0.60**	**400**	1855.080	1852.093		
60	K37 + 610	K38 + 010	**-1.60**	**400**	1852.093	1846.464		
61	K38 + 010	K38 + 830	**-0.35**	**820**	1846.464	1843.531		
62	K38 + 830	K39 + 580	**0.44**	**750**	1843.531	1846.415		
63	K39 + 580	K40 + 140	**0.00**	**560**	1846.415	1846.729		
64	K40 + 140	K40 + 540	**0.51**	**400**	1846.729	1848.103		
65	K40 + 540	K40 + 940	**-0.90**	**400**	1848.103	1845.221		
66	K40 + 940	K41 + 450	**-0.20**	**510**	1845.221	1843.885		
67	K41 + 450	K41 + 870	**-0.40**	**420**	1843.885	1842.095		
68	K41 + 870	K42 + 290	**-0.85**	**420**	1842.095	1838.960		
69	K42 + 290	K42 + 790	**0.00**	**500**	1838.960	1838.254		
70	K42 + 790	K43 + 430	**-1.20**	**640**	1838.254	1831.532		
71	K43 + 430	K44 + 300	**0.00**	**870**	1831.532	1827.650		
72	K44 + 300	K44 + 970	**-4.00**	**670**	1827.650	1805.040		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
73	K44 + 970	K45 + 690	**-1.35**	**720**	1805.040	1793.842	**Basic Freeway Segment**	
74	K45 + 690	K46 + 150	**-2.65**	**460**	1793.842	1782.474		
75	K46 + 150	K46 + 740	**-1.60**	**590**	1782.474	1774.487		
76	K46 + 740	K47 + 400	**3.00**	**660**	1774.487	1790.674		
77	K47 + 400	K48 + 270	**0.68**	**870**	1790.674	1797.625		
78	K48 + 270	K48 + 670	**-1.40**	**400**	1797.625	1795.305		
79	K48 + 670	K49 + 070	**4.00**	**400**	1795.305	1808.980		
80	K49 + 070	K49 + 960	**1.70**	**890**	1808.980	1821.654		
81	K49 + 960	K50 + 410	**-1.70**	**450**	1821.654	1818.423		
82	K50 + 410	K50 + 960	**3.30**	**550**	1818.423	1831.856		
83	K50 + 960	K51 + 610	**-0.30**	**650**	1831.856	1832.980		
84	K51 + 610	K52 + 080	**0.60**	**470**	1832.980	1835.379	At K51 + 800, Modjo Interchange Begin Point At K53 + 100, Modjo Interchange End Point	
85	K52 + 080	K52 + 700	**0.30**	**620**	1835.379	1833.768		
86	K52 + 700	K53 + 440	**-3.80**	**740**	1833.768	1812.688		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
87	K53 + 440	K54 + 000	**3.00**	**560**	1812.688	1826.520	**Basic freeway Segment**	
88	K54 + 000	K54 + 700	**4.00**	**700**	1826.520	1850.091		
89	K54 + 700	K55 + 340	**-3.00**	**640**	1850.091	1852.996		
90	K55 + 340	K56 + 170	**2.90**	**830**	1852.996	1871.422		> 2 - 3 % of Grade
91	K56 + 170	K56 + 790	**-2.15**	**620**	1871.422	1863.605		
92	K56 + 790	K57 + 270	**0.45**	**480**	1863.605	1865.576		
93	K57 + 270	K57 + 700	**2.00**	**430**	1865.576	1872.371		
94	K57 + 700	K58 + 100	**-0.86**	**400**	1872.371	1868.010		
95	K58 + 100	K59 + 190	**-5.00**	**1090**	1868.010	1816.213		
96	K59 + 190	K59 + 810	**-1.80**	**620**	1816.213	1803.545	At K59 + 400 (Adama West - Interchange Start Point) & At K60 + 600 (Adama West - Interchange End Point)	
97	K59 + 810	K60 + 790	**-5.00**	**980**	1803.545	1755.746		
98	K60 + 790	K61 + 190	**-2.50**	**400**	1755.746	1744.329	**Basic freeway Segment**	
99	K61 + 190	K62 + 140	**-5.00**	**950**	1744.329	1699.647		
100	K62 + 140	K62 + 850	**-0.30**	**710**	1699.647	1692.829		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
101	K62 + 850	K64 + 050	**-5.00**	**1200**	1692.829	1639.393	**Basic freeway Segment**	
102	K64 + 050	K64 + 930	**2.00**	**880**	1639.393	1647.535	At K64 + 500 Up To At K65 + 500 (Toll Plaza)	
103	K64 + 930	K65 + 520	**-4.80**	**590**	1647.535	1625.928		
104	K65 + 520	K65 + 920	**-1.80**	**400**	1625.928	1617.848	**Basic Freeway Segment**	
105	K65 + 920	K66 + 340	**-2.15**	**420**	1617.848	1608.860		
106	K66 + 340	K66 + 780	**-2.35**	**440**	1608.860	1599.191	At K66 + 500 (Wonji Road Interchange Start Point) & At K68 + 100 (Wonji Road Interchange End Point)	
107	K66 + 780	K67 + 585	**0.00**	**805**	1599.191	1600.277		
108	K67 + 585	K68 + 120	**4.20**	**535**	1600.277	1620.807		
109	K68 + 120	K68 + 700	**3.30**	**580**	1620.807	1639.694	**Basic Freeway Segment**	
110	K68 + 700	K69 + 270	**1.50**	**570**	1639.694	1648.130		
111	K69 + 270	K70 + 020	**-0.75**	**750**	1648.130	1643.024		
112	K70 + 020	K70 + 520	**-1.07**	**500**	1643.024	1638.153		

No	Chainage		Grade (%)	length of grade (m)	Profile Level (m)		Expressway segment type	Location selected for
	Start	End			Start	End		
113	K70 + 520	K70 + 920	**0.30**	**400**	1638.153	1638.315	At K70 + 900 (Asela Road Interchange Start Point) & At K72 + 400 (Asela Road Interchange End Point)	
114	K70 + 920	K71 + 320	**-1.90**	**400**	1638.315	1631.870		
115	K71 + 320	K71 + 750	**-0.50**	**430**	1631.870	1628.516		
116	K71 + 750	K72 + 150	**-2.15**	**400**	1628.516	1620.983		
117	K72 + 150	K72 + 560	**-0.30**	**410**	1620.983	1619.167		
118	K72 + 560	K73 + 010	**-1.20**	**450**	1619.167	1614.162	**Basic Freeway Segment**	
119	K73 + 010	K73 + 600	**-0.40**	**590**	1614.162	1611.460		
120	K73 + 600	K74 + 100	**-1.00**	**500**	1611.460	1604.640		
121	K74 + 100	K74 + 700	**-5.00**	**600**	1604.640	1577.593		
122	K74 + 700	K75 + 510	**-1.70**	**810**	1577.593	1562.348		
123	K75 + 510	K75 + 930	**-2.70**	**420**	1562.348	1551.976		
124	K75 + 930	K76 + 490	**-0.40**	**560**	1551.976	1548.049		
125	K76 + 490	K77 + 000	**-3.40**	**710**	1547.970	1531.950	**K77 + 000 (End of Strech begin point)**	

Appendix B

Data collection Sheet

Page No. 12

General information for the site location

Data collector : Belay

Purpose of collection : for study

Date of collection : May 19, 2016

Time of collection : Start at 09:30 AM , End at 12:30 PM

Weather condition : Clear

Pavement condition : very good

Traffic incidents/disabled vehicles : Yes ☐ No ☒

Site location

Name of Highway : Addis Ababa – Adama Expressway

GPS data on the data collection site

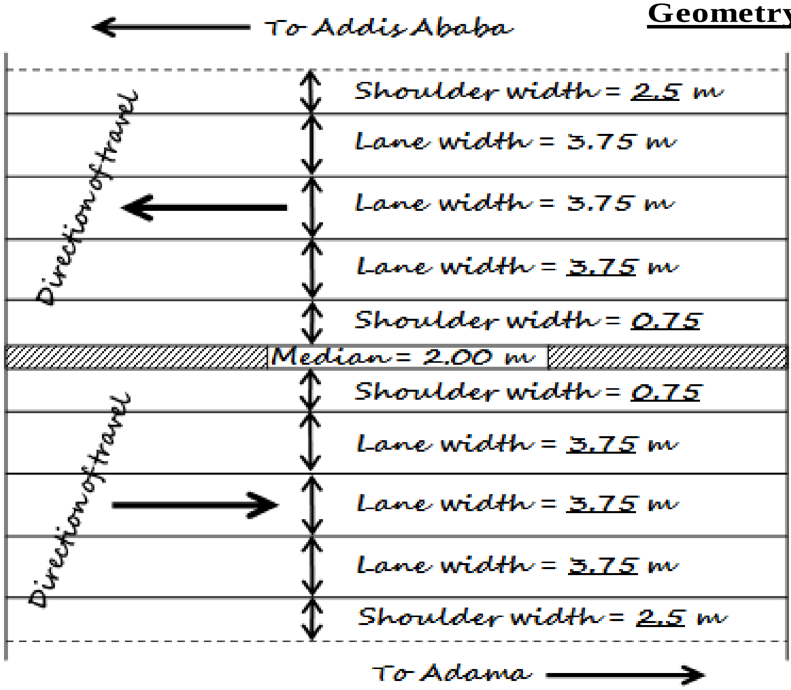
Easting : 38.88804167

Northing : 8.83399414

Elevation : 2064.72 m

Chainage : K10+390 (> 4-5% & 0.0-0.4 km)

Geometry of the site location



Grade type : Upgrade

Number of lane : 6 (Six)

Lane width : 3.75 m

Lateral clearance : 2.5 m

Direction of travel : Adama – Addis ababa

Recorded video data link name : VID_20160519_043303

Appendix C

Data collected for Free Flow Speed

Data was collected at K26+650 (≤ 2% and > 0.8 – 1.2 km) in Adama – Addis Ababa direction of flow for 15 minutes under conditions of low volume

No	Distance (m)	Time (sec)	Type of vehicle
1	50	2.10	TOYOTA DX
2	50	1.79	TOYOTA DX
3	50	2.43	TOYOTA KINCAP
4	50	2.29	TOYOTA DX
5	50	2.76	TOYOTA DX
6	50	1.59	TOYOTA Dolphin Hiace
7	50	1.65	TOYOTA KINCAP
8	50	2.04	TOYOTA 3F
9	50	1.65	TOYOTA Hiace Minibus
10	50	1.84	TOYOTA Hilux Minibus
11	50	1.39	TOYOTA Executive
12	50	1.77	Mini Van
13	50	2.82	TOYOTA 3F
14	50	1.79	TOYOTA Hilux Minibus
15	50	2.12	NISSAN Pickup
16	50	2.11	Mini Van
17	50	1.86	TOYOTA Hiace Minibus
18	50	1.38	CHEVROLET Cruze
19	50	1.98	Station Wagon
20	50	2.90	TOYOTA KINCAP
21	50	1.65	TOYOTA Hiace Minibus
22	50	1.92	TOYOTA 3F
23	50	1.78	Station Wagon
24	50	1.85	TOYOTA PRADO
25	50	2.10	NISSAN Pickup
26	50	1.33	TOYOTA Hilux Pickup
27	50	1.33	TOYOTA Hilux Pickup
28	50	1.91	TOYOTA 3F
29	50	1.71	TOYOTA Hiace Minibus
30	50	2.17	TOYOTA Hiace Minibus

No	Distance (m)	Time (sec)	Type of vehicle
31	50	1.78	TOYOTA Hiace Minibus
32	50	1.85	TOYOTA V8
33	50	1.97	TOYOTA KINCAP
34	50	1.53	TOYOTA Dolphin Hiace
35	50	1.98	TOYOTA Executive
36	50	3.74	TOYOTA KINCAP
37	50	1.97	TOYOTA Hiace Minibus
38	50	1.78	TOYOTA Hilux Pickup
39	50	1.39	TOYOTA Hilux Minibus
40	50	1.65	TOYOTA Dolphin Hiace
41	50	1.39	NISSAN Pickup
42	50	1.92	TOYOTA 3F
43	50	1.52	TOYOTA Hilux Minibus
44	50	1.91	TOYOTA Hilux Minibus
45	50	2.17	LIFAN 620
46	50	1.92	TOYOTA Dolphin Hiace
47	50	2.63	TOYOTA KINCAP
48	50	1.39	FORD RANGER Pickup
49	50	1.44	TOYOTA Hilux Minibus
50	50	1.65	TOYOTA DX
51	50	1.59	NISSAN Lorry
52	50	2.50	TOYOTA DX
53	50	1.52	TOYOTA Dolphin Hiace

Σ of time = 101.20 Sec.

The distance was measured on the road way by using steel tape and made a marking on the roadway, and the time was measured when the vehicle passes that distance by recording the time taken to pass that distance and recording the time.

$$\text{Space Mean Speed} = \frac{d}{\left(\frac{\sum_i t_i}{n}\right)} = \frac{\text{Distance traversed in m.}}{\left(\frac{\text{time for vehicle "i" to traverse the section in Sec.}}{\text{number of observed vehicles}}\right)}$$

$$\text{Space Mean Speed} = \frac{50\text{ m.}}{\left(\frac{101.20\text{ sec.}}{53}\right)} = 26.19\text{ m/sec.}$$

Space mean = 26.19 m/sec. X 3.6 = **94.28 km/hr** so, the Free Flow Speed was **94 km/hr**

Appendix D

The summarized executed PCEs values for upgrade and downgrade tabulated as follows:

Summarized PCEs for Trucks and Buses (E_T) on Upgrades

Upgrade (%)	Length (km)	Proportion of Trucks and Buses (8% - 12%) 10%	(13% - 17%) 15%	(18% - 22%) 20%	(23% - 27%) 25%	(28% - 32%) 30%	(33% - 37%) 35%	(38% - 42%) 40%	(43% - 47%) 45%	(48% - 52%) 50%
≤ 2	0.0 - 0.4	10% = 3.1 **3.1**	17% = 2.8 **2.8**	20% = 3.6 20% = 1.1 avg. **2.4**	23% = 2.2 25% = 1.7 avg. **2.0**	29% = 2.3 30% = 1.5 avg. **1.9**	33% = 1.9 avg. **1.9**	42% = 1.9 **1.9**	44% = 1.7 **1.7**	50% = 1.4 **1.4**
	> 0.4 - 0.8	10% = 2.4 11% = 4.8 avg. **3.6**	13% = 2.6 14% = 3.4 avg. **3.0**	20% = 3.8 21% = 1.5 avg. **2.7**	25% = 3.1 25% = 2.1 avg. **2.6**	30% = 2.3 **2.3**	33% = 2.3 **2.3**	39% = 1.7 40% = 2.3 avg. **2.0**	43% = 1.3 46% = 2.3 avg. **1.8**	50% = 1.4 **1.4**
	> 0.8 - 1.2	12% = 3.9 **3.9**	13% = 3.4 **3.4**	21% = 3.3 22% = 2.4 avg. **2.9**	23% = 3.3 25% = 1.8 avg. **2.6**	28% = 2.2 28% = 1.7 29% = 3.8 avg. **2.5**	33% = 3.5 36% = 1.3 avg. **2.4**	38% = 2.0 **2.0**	46% = 1.9 **1.9**	50% = 1.5 **1.5**
	> 1.2 - 1.6	11% = 3.9 **3.9**	17% = 3.5 **3.5**	21% = 3.4 **3.4**	24% = 2.8 **2.8**	32% = 2.6 **2.6**	35% = 2.5 **2.5**	38% = 3.3 42% = 1.5 avg. **2.4**	46% = 2.1 **2.1**	50% = 1.0 50% = 2.1 avg. **1.6**
> 2-3	0.0 - 0.4	11% = 2.8 **2.8**	15% = 2.5 **2.5**	21% = 2.3 **2.3**	25% = 2.6 25% = 1.5 avg. **2.1**	28% = 2.3 29% = 1.5 avg. **1.9**	35% = 1.2 37% = 2.0 avg. **1.6**	38% = 1.4 40% = 1.8 avg. **1.6**	43% = 1.6 **1.6**	49% = 1.4 **1.4**
	> 0.4 - 0.8	11% = 3.5 **3.5**	15% = 2.0 15% = 3.5 avg. **2.8**	18% = 2.5 **2.5**	25% = 2.4 **2.4**	30% = 1.3 30% = 2.7 avg. **2.0**	36% = 1.8 **1.8**	41% = 1.7 **1.7**	43% = 1.5 44% = 1.8 avg. **1.7**	48% = 1.6 **1.6**
> 3-4	0.0 - 0.4	10% = 3.8 **3.8**	15% = 3.1 **3.1**	19% = 2.3 **2.3**	27% = 2.2 **2.2**	32% = 2.1 30% = 1.7 avg. **1.9**	33% = 2.2 37% = 1.4 avg. **1.8**	40% = 1.8 **1.8**	45% = 1.3 46% = 2.0 avg. **1.7**	50% = 1.5 **1.5**
	> 0.4 - 0.8	10% = 4.0 **4.0**	15% = 3.7 **3.7**	20% = 2.8 **2.8**	26% = 2.4 26% = 3.0 avg. **2.7**	30% = 2.0 **2.0**	34% = 2.3 36% = 1.7 avg. **2.0**	39% = 1.9 **1.9**	45% = 1.8 **1.8**	50% = 1.7 **1.7**
	> 0.8 - 1.2	10% = 3.5 11% = 5.8 avg. **4.7**	15% = 5.5 17% = 2.0 **3.8**	18% = 3.3 **3.3**	25% = 3.3 **3.3**	32% = 2.7 **2.7**	35% = 2.5 **2.5**	39% = 2.3 **2.3**	46% = 2.3 **2.3**	50% = 2.1 50% = 1.3 **1.7**
	> 1.2 - 1.6	10% = 5.2 **5.2**	13% = 6.2 15% = 4.0 avg. **5.1**	20% = 4.9 **4.9**	24% = 3.5 25% = 4.3 avg. **3.9**	31% = 2.7 **2.7**	36% = 2.6 **2.6**	38% = 2.5 40% = 2.6 avg. **2.6**	47% = 2.0 **2.0**	50% = 2.5 50% = 1.2 **1.9**
> 4-5	0.0 - 0.4	10% = 5.6 **5.6**	17% = 5.2 **5.2**	20% = 4.8 22% = 3.2 avg. **4.0**	26% = 3.7 **3.7**	28% = 3.5 **3.5**	34% = 2.4 36% = 3.1 avg. **2.8**	39% = 2.6 **2.6**	46% = 2.1 **2.1**	50% = 1.5 **1.5**
	> 0.4 - 0.8	10% = 6.2 **6.2**	17% = 5.3 **5.3**	20% = 4.3 **4.3**	27% = 3.8 **3.8**	31% = 3.1 31% = 4.4 avg. **3.8**	34% = 3.7 **3.7**	39% = 2.9 **2.9**	44% = 2.4 **2.4**	50% = 1.7 **1.7**
	> 0.8 - 1.2	10% = 6.9 **6.9**	15% = 8.7 16% = 4.2 avg. **6.5**	19% = 5.9 21% = 4.9 avg. **5.4**	23% = 7.4 23% = 3.3 26% = 4.2 avg. **5.0**	30% = 4.5 **4.5**	33% = 3.9 **3.9**	42% = 3.5 **3.5**	47% = 2.6 **2.6**	50% = 1.7 **1.7**
	> 1.2 - 1.6	9% = 6.8 10% = 8.7 avg. **7.8**	16% = 7.1 **7.1**	18% = 7.9 21% = 5.4 avg. **6.7**	23% = 5.5 **5.5**	30% = 5.3 **5.3**	33% = 3.6 33% = 5.0 avg. **4.3**	41% = 3.5 **3.5**	43% = 2.7 **2.7**	50% = 2.0 **2.0**

Summarized PCEs for Trucks and Buses (E_T) on Downgrades

Downgrade (%)	Length (km)	Proportion of Trucks and Buses (8% - 12%) 10%	(13% - 17%) 15%	(18% - 22%) 20%	(23% - 27%) 25%	(28% - 32%) 30%	(33% - 37%) 35%	(38% - 42%) 40%	(43% - 47%) 45%	(48% - 52%) 50%
< 4	≤ 0.8	10% = 4.7 10% = 1.0 avg. **2.9**	13% = 2.4 14% = 3.2 avg. **2.8**	19% = 2.0 22% = 2.8 avg. **2.4**	24% = 2.6 27% = 2.0 avg. **2.3**	28% = 2.7 29% = 1.2 29% = 2.2 avg. **2.0**	36% = 2.1 36% = 1.7 avg. **1.9**	40% = 1.8 **1.8**	46% = 1.1 46% = 2.1 avg. **1.6**	50% = 2.2 50% = 1.2 50% = 1.1 avg. **1.5**
4 - 5	≤ 1.2	10% = 3.7 11% = 2.2 avg. **3.0**	15% = 2.9 **2.9**	20% = 1.1 20% = 3.8 avg. **2.5**	26% = 3.1 26% = 2.3 27% = 1.9 avg. **2.4**	28% = 2.3 31% = 1.6 avg. **2.0**	36% = 2.0 **2.0**	38% = 2.1 41% = 1.6 avg. **1.9**	43% = 2.0 46% = 1.4 avg. **1.7**	50% = 1.9 50% = 1.0 avg. **1.5**

Transformed field video recorded data of vehicles to the tabular form on

Addis Ababa – Adama Expressway

Section Page No: 1

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : ≥ 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 10:06:45 AM Ending time : 10:07:57 AM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

For Base Flow

1.2 Min. = 12 Veh.

15 Min. = X

X = 150 Veh.

- For Base flow, number of vehicles for 15 min.	150 veh.

Time on video : 00:36:45 Up to 00:37:57

On video : 1 of 2

Transformed field video recorded data of vehicles to the tabular form on

Addis Ababa – Adama Expressway

Section Page No: 2

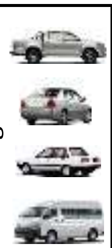
Grade type : [X] Upgrade [ ] Downgrade

Grade percent : ≥ 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 11:02:13 AM Ending time : 11:03:49 AM

Traffic flow direction : Adama - Addis Ababa

Passenger car



~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

For Passenger Car

1.6 Min. = 10 Veh.

15 Min. = X

X = 94 Veh.

For Heavy Vehicles

1.6 Min. = 1 Veh.

15 Min. = X

X = 10 Veh.

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(94 + 10) 104 veh.
- Only heavy vehicles in No for 15 min.	10 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
10%	5.6

Time on video : 00:47:13 Up to 00:48:49

On video : 2 of 2

Transformed field video recorded data of vehicles to the tabular form on
Addis Ababa – Adama Expressway

Section Page No: 3

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : ≥ 4-5%   Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 10:15:00 AM   Ending time : 10:30:00 AM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	~~56~~	~~57~~	~~58~~	~~59~~	~~60~~	~~61~~	~~62~~	~~63~~	~~64~~	~~65~~	~~66~~	~~67~~	~~68~~
~~69~~	~~70~~	~~71~~	~~72~~	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(72 + 15) 87 veh.
- Only heavy vehicles in No for 15 min.	15 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
17%	5.2

Time on video : 00:45:00   Up to 00:60:00

On video : 1 of 2

Transformed field video recorded data of vehicles to the tabular form on
Addis Ababa – Adama Expressway

Section Page No: 4

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : ≥ 4-5%   Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 10:00:00 AM   Ending time : 10:15:00 AM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	~~56~~	~~57~~	~~58~~	~~59~~	~~60~~	~~61~~	~~62~~	~~63~~	~~64~~	~~65~~	~~66~~	~~67~~	~~68~~
~~69~~	~~70~~	~~71~~	~~72~~	~~73~~	~~74~~	~~75~~	~~76~~	~~77~~	~~78~~	~~79~~	~~80~~	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(80 + 22) 102 veh.
- Only heavy vehicles in No for 15 min.	22 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
22%	3.2

Time on video : 00:30:00   Up to 00:45:00

On video : 1 of 2

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 5

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : > 4-5%

Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 10:20:06 AM

Ending time : 10:22:46 AM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	4	5	6	7	8	9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Time on video : 00:50:06 Up to 00:52:46

On video : 1 of 2

For Passenger Car

2.67 Min. = 12 Veh.

15 Min. = X

X = 68 Veh.

For Heavy Vehicles

2.67 Min. = 3 Veh.

15 Min. = X

X = 17 Veh.

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(68 + 17) 85 veh.
- Only heavy vehicles in No for 15 min.	17 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
20%	4.8

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 6

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : > 4-5%

Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 12:00:00 PM

Ending time : 12:15:00 PM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	~~56~~	~~57~~	~~58~~	~~59~~	~~60~~	~~61~~	~~62~~	~~63~~	~~64~~	~~65~~	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Time on video : 00:30:00 Up to 00:45:00

On video : 2 of 2

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(65 + 23) 88 veh.
- Only heavy vehicles in No for 15 min.	23 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
26%	3.7

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 7

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : > 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 12:30:00 PM Ending time : 12:45:00 PM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	~~56~~	~~57~~	~~58~~	~~59~~	~~60~~	~~61~~	~~62~~	~~63~~	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(63 + 25) 88 veh.
- Only heavy vehicles in No for 15 min.	25 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
28%	3.5

Time on video : 00:00:00 Up to 00:15:00

On video : 2 of 2

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 8

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : > 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 10:45:00 AM Ending time : 11:00:00 AM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	~~56~~	~~57~~	~~58~~	~~59~~	~~60~~	~~61~~	~~62~~	~~63~~	~~64~~	~~65~~	~~66~~	~~67~~	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(67 + 34) 101 veh.
- Only heavy vehicles in No for 15 min.	34 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
34%	2.4

Time on video : 00:15:00 Up to 00:30:00

On video : 1 of 2

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 9

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : ≥ 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 11:45:00 AM Ending time : 12:00:00 PM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Time on video : 00:15:00 Up to 00:30:00

On video : 2 of 2

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(55 + 31) 86 veh.
- Only heavy vehicles in No for 15 min.	31 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
36%	3.1

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 10

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : ≥ 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 12:15:00 PM Ending time : 12:30:00 PM

Traffic flow direction : Adama - Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	~~37~~	~~38~~	~~39~~	~~40~~	~~41~~	~~42~~	~~43~~	~~44~~	~~45~~	~~46~~	~~47~~	~~48~~	~~49~~	~~50~~	~~51~~
~~52~~	~~53~~	~~54~~	~~55~~	~~56~~	~~57~~	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~18~~	~~19~~	~~20~~	~~21~~	~~22~~	~~23~~	~~24~~	~~25~~	~~26~~	~~27~~	~~28~~	~~29~~	~~30~~	~~31~~	~~32~~	~~33~~	~~34~~
~~35~~	~~36~~	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Time on video : 00:45:00 Up to 00:60:00

On video : 2 of 2

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(57 + 36) 93 veh.
- Only heavy vehicles in No for 15 min.	36 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
39%	2.6

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 11

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : > 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 10:36:22 AM Ending time : 10:38:01 AM

Traffic flow direction : Adama – Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	7	8	9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	6	7	8	9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Time on video : 00:21:22 Up to 00:23:01

On video : 2 of 2

For Passenger Car

1.65 Min. = 6 Veh.
15 Min. = X
X = 55 Veh.

For Heavy Vehicles

1.65 Min. = 5 Veh.
15 Min. = X
X = 46 Veh.

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(55 + 46) 101 veh.
- Only heavy vehicles in No for 15 min.	46 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
46%	2.1

Transformed field video recorded data of vehicles to the tabular form on Addis Ababa – Adama Expressway

Section Page No: 12

Grade type : [X] Upgrade [ ] Downgrade

Grade percent : > 4-5% Length of grade : 0.0-0.4km (@ K10+390)

Starting time : 9:37:26 AM Ending time : 9:38:56 AM

Traffic flow direction : Adama – Addis Ababa

Passenger car

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	7	8	9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Heavy vehicles

~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	7	8	9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
86	87	88	89	90	91	92	93	94	95	96	97	98	99	100		

Time on video : 00:07:26 Up to 00:08:56

On video : 1 of 2

For Passenger Car

1.5 Min. = 6 Veh.
15 Min. = X
X = 60 Veh.

For Heavy Vehicles

1.5 Min. = 6 Veh.
15 Min. = X
X = 60 Veh.

- For Base flow, number of vehicles for 15 min.	150 veh.
- Passenger car & Heavy vehicles in No for 15 min.	(60 + 60) 120 veh.
- Only heavy vehicles in No for 15 min.	60 veh.

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

Inserting into the above formula and the output values are:

Percentage	Value of E_T
50%	1.5

Appendix E

Sample calculation to determine Passenger Car Equivalents

In Addis Ababa-Adama Expressway; the collected data on the date of May 24, 2016 at a time of 11:45:00 AM up to 12:00:00 PM with an upgrade percent of > 4 - 5 and a length of grade with > 0.8 – 1.2 km was as follows:

Counted base vehicles (passenger car only) = 171 Veh.

Counted mixed vehicles (trucks and buses, and passenger cars) = 83 Veh.

Counted trucks and buses = 35 Veh.

Computation

$$\text{Base flow rate}(q_B) = \frac{\text{Counted base vehicles (veh.)}}{\text{15 min (0.25 hr)}} = \frac{\text{171 veh.}}{\text{0.25 hr}} = \mathbf{684\ veh/hr}$$

$$\text{Mixed flow rate}(q_M) = \frac{\text{Counted mixed vehicles (veh.)}}{\text{15 min (0.25 hr)}} = \frac{\text{83 veh.}}{\text{0.25 hr}} = \mathbf{332\ veh/hr}$$

$\Rightarrow$ Counted mixed vehicles (veh) = 100 %, Counted trucks and buses (veh) = α } 83 veh = 100 %, 35 veh = α } α = **42 %**

$\Rightarrow$ Counted trucks and buses percentage was 42 % = 0.42

Then calculating the Passenger Car Equivalents (E_T) will be:

$$E_T = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1 = \frac{1}{0.42}\left(\frac{\text{684 veh/hr}}{\text{332 veh/hr}} - 1\right) + 1$$

$\mathbf{E_T} = \underline{\mathbf{3.5}}$

Appendix F

Example problem

Operational analysis

To determine Six-lane freeway LOS (Addis Ababa – Adama Expressway)

Data

- ✓ Six-lane freeway (three lanes in each direction);
- ✓ Lane width = 3.75 m;
- ✓ Right side lateral clearance = 2.5 m;
- ✓ Commuter traffic (regular users);
- ✓ Peak-hour, peak-direction demand volume = 311 veh/h;
- ✓ Traffic composition: 10% trucks, 0% RVs;
- ✓ Length of Grade: > 0.8 – 1.2 km; and
- ✓ Grade percent: ≤ 2%.

The task is to find the expected LOS for this freeway during the worst 15 min of the peak hour.

Computation

The Free Flow Speed (FFS) estimated in Appendix C.

The FFS of the freeway was estimated as:

FFS = 94 km/hr.

Select FFS curve

According to HCM 2010 (on page 11-4), the FFS ranges as follows:

≥ 72.5 mi/h < 77.5 mi/h: use FFS = 75 mi/h

≥ 67.5 mi/h < 72.5 mi/h: use FFS = 70 mi/h

≥ 62.5 mi/h < 67.5 mi/h: use FFS = 65 mi/h

≥ 57.5 mi/h < 62.5 mi/h: use FFS = 60 mi/h

≥ 52.5 mi/h < 57.5 mi/h: use FFS = 55 mi/h

So, FFS = 94 km/hr. = **58 mi/h**

As the FFS is greater than or equal to 57.5 and less than 62.5 mi/h, the 60 mi/h speed-flow curve will be used for this analysis.

From the collected data the peak hour factor (PHF) calculated as:

$$\text{PHF} = \frac{\text{V}}{4 \text{ X } \text{V}_{\text{m15}}} = \frac{\text{hourly volume,vehs}}{4 \text{ X maximum 15}-\text{minute volume within the hours,vehs}}$$

Time Interval	Volume for time Interval (vehs)
11:00 AM - 11:15 AM	74
11:15 AM - 11:30 AM	83
11:30 AM - 11:45 AM	73
11:45 AM - 12:00 PM	81
11:00 AM - 12:00 PM	Σ = 311

$$\text{PHF} = \frac{\text{V}}{4 \text{ X } \text{V}_{\text{m15}}} = \frac{311 \text{ vehs}}{4 \text{ X } 83 \text{ vehs}} = 0.94$$

The heavy vehicle adjustment factor is computed by using equation 2.6:

$$\text{f}_{\text{HV}} = \frac{1}{1 + \text{P}_{\text{T}}(\text{E}_{\text{T}} - 1) + \text{P}_{\text{R}}(\text{E}_{\text{R}} - 1)}$$

By using executed PCE

$$\text{f}_{\text{HV}} = \frac{1}{1 + \text{P}_{\text{T}}(\text{E}_{\text{T}} - 1) + \text{P}_{\text{R}}(\text{E}_{\text{R}} - 1)}$$

$$\text{f}_{\text{HV}} = \frac{1}{1 + 0.1(3.9 - 1) + 0} = 0.775$$

Adjust demand volume

The demand volume must be adjusted to a flow rate that reflects passenger cars per hour per lane by using equation 2.1:

$$v_p = \frac{V}{PHF \ X \ N \ X \ f_{HV} \ X \ f_p}$$

The demand volume is 311veh/h and there are three lanes in each direction. The driver population factor is 1.00, since regular users (commuters) are specified.

Then

$$\text{v}_{\text{p}} = \frac{311}{0.94 \text{ X } 3 \text{ X } 0.775 \text{ X } 1.00} = 143 \text{ pc/h/ln}$$

Since this value is less than the base capacity of 2,300 pc/h/ln (Exhibit 11-2 HCM 2010, on page 11-3) for a freeway with FFS = 60 mi/h, LOS F does not exist, and the analysis continues to estimate speed and density.

Estimate speed and density

The FFS of the basic freeway segment is now estimated along with the demand flow rate in passenger cars per lane under equivalent base conditions. From exhibit 11-3 HCM 2010, on page 11-4, the equation for estimating the speed of the traffic stream is selected for a 60 mi/h FFS, with a flow rate less than 1600 pc/h/ln. This is the constant speed portion of the curve, so S = 60 mi/h. The density of the traffic stream may now be computed as:

$$D = \frac{v_p}{S} = \frac{143}{60} = 2.4 \text{ pc/mi/ln}$$

Determine LOS

According to HCM 2010 (on page 11-7), the LOS criteria for basic freeway segments as follows:

LOS	**Density (pc/mi/ln)**
A	≤ 11
B	> 11 - 18
C	> 18 - 26
D	> 26 - 35
E	> 35 - 45
F	Demand exceeds capacity > 45

A density of 2.4 pc/mi/ln corresponds to LOS A.

By using HCM 2010 PCE

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

$$f_{HV} = \frac{1}{1 + 0.1(1.5 - 1) + 0} = 0.952$$

Adjust demand volume

The demand volume must be adjusted to a flow rate that reflects passenger cars per hour per lane by using equation 2.1:

$$v_p = \frac{V}{PHF\ X\ N\ X\ f_{HV}\ \ X\ f_p}$$

The demand volume is 311 veh/h, and there are three lanes in each direction. The driver population factor is 1.00, since regular users (commuters) are specified.

Then

$$\mathrm{v_p} = \frac{311}{0.94\ \mathrm{X}\ 3\ \mathrm{X}\ 0.952\ \mathrm{X}\ 1.00} = 116\ \mathrm{pc/h/ln}$$

Since this value is less than the base capacity of 2,300 pc/h/ln (Exhibit 11-2 HCM 2010, on page 11-3) for a freeway with FFS = 60 mi/h, LOS F does not exist, and the analysis continues to estimate speed and density.

Estimate speed and density

The FFS of the basic freeway segment is now estimated along with the demand flow rate in passenger cars per lane under equivalent base conditions. From exhibit 11-3 HCM 2010, on page 11-4, the equation for estimating the speed of the traffic stream is selected for a 60 mi/h FFS, with a flow rate less than 1600 pc/h/ln. This is the constant speed portion of the curve, so S = 60 mi/h. The density of the traffic stream may now be computed as:

$$\mathrm{D} = \frac{\mathrm{v_p}}{\mathrm{S}} = \frac{116}{60} = 1.9\ \mathrm{pc/mi/ln}$$

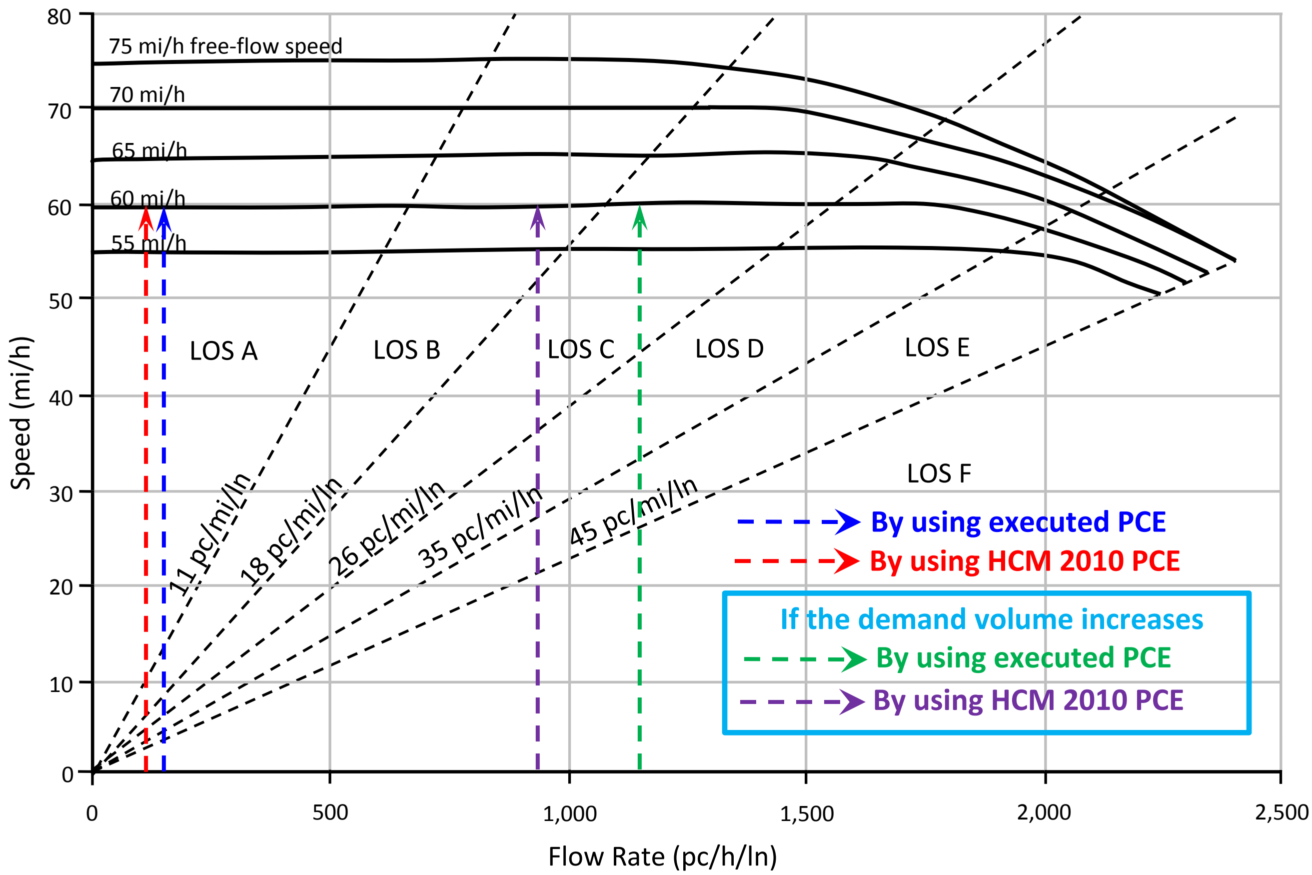
Determine LOS

According to HCM 2010 (on page 11-7), the LOS criteria for basic freeway segments as follows:

LOS	**Density (pc/mi/ln)**
A	≤ 11
B	> 11 - 18
C	> 18 - 26
D	> 26 - 35
E	> 35 - 45
F	Demand exceeds capacity > 45

A density of 1.9 pc/mi/ln corresponds to LOS A.

These two solutions also shown graphically as follows:



Discussion

This basic freeway segment of a six-lane freeway is expected to operate at LOS A during the worst 15 minutes of the peak hour. It is important to note that the operation, although at LOS A. A result from the calculated LOS with the executed PCE value and HCM 2010 provided PCE value shows the LOS A but there is a difference in demand volume as well as density of the traffic stream. So the difference shows the executed PCE gives a better decision in the future according to the local condition while demand volume increases but on the time being the demand volume is small so may not be seen a significant difference.

If the demand volume increases 2,500 veh/h the change in the LOS shows on the figure above and the executed PCE shows a significant change in the LOS.

Appendix G

<u>Sample location where the data was taken</u>

Addis Ababa – Adama Expressway Entrance Gate at Tulu Dimtu Main Toll

Picture at Chainage K4 + 050

Picture at Chainage K9 + 660

Picture at Chainage K9 + 990

Picture at Chainage K26 + 650

Picture at Chainage K56 + 070