

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL
ENGINEERING



**PASSENGER CAR EQUIVALENCE UNDER SEVERAL UPGRADE
ROAD CONDITIONS**

(For Cases under Addis Ababa City)

A Thesis in Road & Transport Engineering

By Alemzewed Sete

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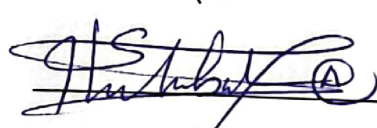

Addis Ababa – Ethiopia

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for Degree of Master of Science in Civil and Environmental Engineering

ADDIS ABABA UNIVERSITY
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SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING



The undersigned have examined the thesis entitled “Passenger Car Equivalence under Several Upgrade Road Conditions (for cases under Addis Ababa City)” Presented by Alemzewed Sete, a candidate for the degree of Master of Science in Road and Transport Engineering and hereby certify that it is worthy of acceptance.

Bikila Teklu (Ph.D)		3/4/24
Advisor	Signature	Date
Mr.Messay Shemsu		29/1/24
Co. Advisor	Signature	Date
Abel Kebede (Ph.D)		01/03/24
Internal Examiner	Signature	Date
Mr.Seid Endriጃ		15/03/24
External Examiner	Signature	Date
Chair person		
Chair person	Signature	Date

Abraham Gebre (Dr.)
Dean, School of Civil &
Environmental Engineering



UNDERTAKING

I certify that research Project titled “Passenger Car Equivalence under Several Upgrade Road Conditions (for cases under Addis Ababa City)” is the result of my own effort. The work has not been submitted for evaluation elsewhere. Proper acknowledgment and references have been provided for any materials sourced from external references.

Alemzewed Sete

ABSTRACT

In developed countries, extensive studies have been conducted to estimate passenger car equivalence (PCE) values under various road geometry, traffic characteristics, and lane width conditions. However, it is important to note that these PCE values may not directly apply to local conditions in Ethiopia since Ethiopia possesses a distinct traffic environment characterized by heterogeneous traffic conditions, diverse road geometries, and unique traffic characteristics. Therefore, relying solely on PCE values derived from studies in developed countries may not accurately reflect the specific conditions and dynamics of Ethiopia's transportation system. There is also a lack of comprehensive understanding regarding the influence of vehicle characteristics in different road configurations in Ethiopia, particularly with respect to PCUs. The Highway Capacity Manual (HCM) of 2010 suggests treating road segments with steep grades separately, given their unique conditions.

This study focuses on estimating Passenger Car Unit (PCU) values for six vehicle types, considering variations in traffic volume, road grade, and road lane configurations in Addis Ababa, Ethiopia. Data collection, conducted between 4:00 am-10:00 pm over four hours on Tuesday, Wednesday, and Thursday, covering both one-lane and three-lane roads in four selected areas. The utilization of an Artificial Neural Network (ANN) model aids in training and predicting speed, while the Dynamic PCE method determines PCE values. Multiple regression analysis established a mathematical relationship between PCE, vehicle type, road grade, and vehicle speed using SPSS software. Results indicate varying PCE values for different vehicle types on one-lane and three-lane urban roads at different grades. Notably, heavy vehicles exhibit higher PCE on one-lane roads, while buses and medium trucks show consistently higher PCE on three-lane roads. In segments with high road grades, there is an inverse speed impact, starting high and concluding low in three-lane segments, and the inverse relationship continues in one-lane segments, starting with low speed and concluding with high speed on a high uphill grade. Moreover, the obtained PC values surpass those presented in the HCM, signifying their suitability for reflecting the current traffic conditions in the studied locality.

Key word: Passenger Car Equivalence (PCE), Artificial neural network (ANN), HCM (Highway Capacity Manual), Statistical Package for the Social Sciences (SPSS)

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LIST OF ABBREVIATIONS

AACRA	-	-	Addis Ababa City Roads Authority
ANN	-	-	Artificial Neural Network
ERA	-	-	Ethiopian Roads Administration
HCM	-	-	Highway Capacity Manual
LOS	-	-	Level of Service
PCE	-	-	Passenger Car Equivalent
PCU	-	-	Passenger Car Unit
HT	-	-	Heavy Truck
MT	-	-	Medium Truck
SPSS	-	-	Statistical Package for the Social Sciences

1. INTRODUCTION

1.1 Background

The road traffic in Addis Ababa, Ethiopia is highly heterogeneous comprising vehicles like Buses, trucks, and automobiles. Nowadays, it is becoming very difficult for vehicles to maintain traffic lanes and forces to occupy any convenient lateral positions over the road width based on the availability at any instant of time due to the highly varying physical dimensions and speed characteristics (Firehun., March, 2019). Passenger car equivalent (PCE) is a unit which is used to adjust heterogeneous traffic flow into an equivalent homogenous flow composed only of passenger cars. Traffic flow refers to the quantity of vehicles traversing a roadway or traffic lane within a given time frame. In instances of diverse traffic conditions, assessing this flow involves transforming the count of individual vehicle types into equivalent passenger car units. (National Research Council (U.S.). Transportation Research Board. 2010) is also defined as “the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions”.

PCE value is the numerical value that is given to a device to change a mixed vehicle traffic stream into a corresponding equivalent traffic stream composed entirely of passenger cars or basic vehicles. There are basic principles which are applied for estimation of PCE values for any of the roadway type identified in capacity analysis procedures. The first principle links the concept passenger car equivalency to the level of service (LOS) concept. The second principle emphasizes the consideration of all factors that contribute to the overall effect of concern vehicles (other than passenger cars) on traffic stream performance. (Raj et al., 2019)

Therefore, the present research aims to estimate passenger car equivalence under several high-grade roads by considering the overall effect of local traffic condition.

1.2 Research Problem

The use of passenger car units (PCUs) for road design and analysis, as derived from the US Highway Capacity Manual, presents a challenge when applied to the unique local conditions in Ethiopia. Traffic characteristics and road geometry vary across countries, (B. P. Saha et al. 2009)making it crucial to have a dedicated manual that accounts for Ethiopia's specific factors, including vehicle volume, speed, composition, and grade conditions. The absence of such a manual poses significant obstacles in effectively addressing congestion, traffic safety, capacity estimation, and Level of Service (LOS) determination.

Considering this, the research presented in this paper aims to address these challenges by focusing on the estimation of PCE values. The study will consider the impact of vehicle volume, travel speed, and vehicle composition on several high-grade roads in Addis Ababa, Ethiopia. By analyzing these factors, the research endeavors to provide more suitable solutions to the problems and contribute to improved congestion mitigation, traffic safety measures, accurate capacity estimation, and reliable LOS determination within the context of Addis Ababa.

1.3 Study justification

Numerous researchers have dedicated their efforts to developing models that explain the relationship between traffic conditions and Passenger Car Equivalences (PCE) within their respective local contexts. These models have been explored and documented in the literature review of this paper. However, in Ethiopia, there remains a scarcity of studies that specifically investigate PCE on multilane roads, intersections, and grade structure roads. Consequently, this research will fill this knowledge gap by concentrating on estimating PCE values for upgrade road structures in Addis Ababa, Ethiopia.

Furthermore, this study aims to serve as a valuable reference for future investigations conducted under local conditions. By providing insights into PCE estimation on upgrade road structures, this research will contribute to a more comprehensive understanding of the relationship between traffic conditions and PCE in Addis Ababa, Ethiopia. Its findings and methodologies are anticipated to serve as a valuable resource for subsequent research endeavors in this field.

1.4 Research objective

The following are the research objectives the researcher hopes to fulfill:

General objective

- Determining the Passenger Car Equivalence (PCE) values for different vehicle types and examining the relationship between road grade and vehicle speed on passenger car equivalence on the selected several upgrade roads in Addis Ababa.

Specific objectives

- Identify and categorize the traffic composition while determining flow rates on selected roads.
- Utilization of an Artificial Neural Network (ANN) model for training and predicting speed
- Develop a standardized Passenger Car Equivalence (PCE) factor.

- Analyze the influence of Road lanes on PCE value.
- Develop a mathematical model relating PCE, vehicle speed, and road grade
- Compare the new Passenger car equivalence value with Highway capacity manual.

1.5 Importance of the Study

If this research attains its goal, it will:

- Provide possible solutions to minimize the factors that influence Passenger Car Equivalence (PCE), enabling more accurate estimation and assessment of PCE values.
- Offer accurate data on the performance of roads in the local condition, allowing for informed decision-making in road design, capacity estimation, and traffic management (signal timing, lane management etc).
- Be a valuable input for the extension of traffic policy design to account for future changes and considerations in road projects. The research outcomes, particularly the derivation of Passenger Car Equivalence (PCE) values, significantly influence policy decisions related to road infrastructure. These decisions encompass design standards, safety measures, and traffic management strategies, where PCE values inform guidelines, safety features, and adjustments to optimize traffic flow. Additionally, PCE informs decisions on infrastructure investment and environmental policies, guiding prioritization, and shaping standards. The research outcomes can inform policy decisions and design guidelines, ensuring that they align with the evolving needs and practices of road infrastructure.

1.6 Scope and Limitations of the Research

This study will analyze the factors that influence the estimation of passenger car equivalence (PCE) under uphill road conditions, specifically in Addis Ababa, Ethiopia. The study will consider multiple variables, including speed, travel time, traffic volume, vehicle composition and road gradient. The aim of the study is to determine the PCE factor by using the data collected from these variables. The focus of the study will be on uphill road structures within the Addis Ababa area.

1.7 Organization of the Thesis

Chapter 2 This section provides a structured breakdown of several critical sub-topics. Firstly, it elucidates the concept of "several upgrades" within the research context. It then delves into the significance of Passenger Car Units (PCU) in relation to these several upgrade road sections. Additionally, it

comprehensively outlines the methodologies employed for estimating the PCU factor, encompassing both international approaches and locally adapted research methods then choose the preferable method for determining the PCU factor.

Chapter 3 This section tells which thing the study is trying to figure out (dependent variable) and which things are being looked at to understand the main thing (independent variables). It involves the careful selection of an area, specifically focusing on uphill sections. For video recording a detailed schedule is established by specifying both the timing and location for recording activities. Furthermore, the chapter defines the specific types of vehicles utilized in this research.

Chapter 4 This chapter delves into the examination of recorded speed data, calculation of 85thile speed and use the of predictive capabilities of Artificial Neural Networks (ANN) for speed estimation. Then determine individual Passenger Car Unit (PCU) values and develop a mathematical model to see the relation between road grade, vehicle speed and PCE. Finally compare their implications within the context of the Highway Capacity Manual (HCM), providing a holistic understanding of the research findings.

Chapter 5 Summarize the empirical facts and observed phenomena which have been documented throughout the paper. Additionally, it offers valuable recommendations for future studies, acknowledging the areas which were unable to explore due to inherent limitations in the research.

2. LITERATURE REVIEW

2.1 Introduction

The concept of passenger car equivalence (PCE) and its determination play a crucial role in transportation engineering and planning, particularly in the context of several up-grade roads. Several up-grade roads are segments of highways or roadways that involve significant changes in grade, typically consisting of long uphill and downhill sections. Understanding the PCE values specific to these road conditions is essential for accurate traffic analysis, capacity estimation, and roadway design.

In this literature review, the aim is to explore the existing research and studies that focus on determining the passenger car equivalence under several upgrade conditions. The objective is to gain insights into the methodologies, factors, and considerations involved in determining PCE values for different types of several upgrade roads. By examining the available literature, the study intends to identify the key parameters and variables that influence PCE calculations and their implications on traffic operations and roadway performance.

The literature review will encompass various aspects, including the definition and significance of passenger car equivalence, methodologies employed to determine PCE values, factors affecting PCE under several upgrade conditions, and the relationship between PCE and other performance measures such as travel speed and traffic flow. Additionally, the research will explore case studies and empirical evidence from previous research that shed light on the practical application of PCE in the context of several upgrade roads.

By delving into the existing literature on passenger car equivalence under several upgrade conditions, this review aims to provide a comprehensive understanding of the topic, identify research gaps, and highlight potential areas for future investigation. The findings of this review will contribute to the body of knowledge in transportation engineering and facilitate more accurate assessments and design considerations for several up-grade roads.

2.2 Several upgrade roads

The term "several upgrade" refers to a specific type of road or highway that experiences a change in grade or elevation over its length. In other words, it is a road segment where the terrain transitions from a lower level to a higher level, typically involving an uphill slope. This type of road can pose unique challenges for traffic management, vehicle performance, and overall transportation efficiency.

The term "several" in "several upgrade" indicates that there are multiple instances or occurrences of such road sections. These road segments may be found in various geographical locations and can vary in terms of length, steepness, and other characteristics.

When studying several up-grade roads, transportation researchers and engineers aim to understand the specific characteristics and behaviors associated with these road sections. This includes examining factors such as the impact of the uphill slope on vehicle performance, the effect on travel speeds and fuel consumption, the influence on traffic flow, and the determination of appropriate design considerations for ensuring safe and efficient transportation.

In summary, several up-grade roads are road segments characterized by a change in grade or elevation, typically involving an uphill slope. The study of these road sections allows researchers and engineers to explore the unique challenges and implications associated with such terrain, ultimately informing transportation planning and design decisions.

In the context of the Highway Capacity Manual (HCM), the term "several upgrade" refers to road sections with varying uphill slopes and lengths that impact traffic flow and capacity. The HCM categorizes several upgrade roads into different types based on their characteristics and their effect on vehicle performance. Here are some common types of several upgrade roads as defined in the HCM:

- **Type I Several Upgrade:** This type involves a continuous uphill slope with a uniform grade throughout the road segment. It typically requires vehicles to exert continuous effort to climb the slope, affecting their speed and fuel consumption.
- **Type II Several Upgrade:** This type consists of a series of steep uphill sections separated by short level or downhill segments. It poses challenges for drivers as they need to accelerate on the downhill portions to maintain momentum and climb the subsequent uphill sections.
- **Type III Several Upgrade:** This type features long, gradual uphill slopes that can extend over significant distances. It allows vehicles to maintain relatively higher speeds compared to Type I and Type II, but still requires continuous power output to overcome the resistance caused by the uphill grade.
- **Type IV Several Upgrade:** This type involves a combination of uphill slopes and horizontal curves. The presence of curves adds complexity to the road section, requiring drivers to adjust their speed and steering while ascending the slope.

The categorization of several up-grade roads in the HCM helps transportation professionals assess the impact of these road sections on traffic operations, capacity, and performance. Understanding the specific type of several upgrade road allows for more accurate analysis and evaluation of traffic flow, travel speeds, and capacity under different conditions and for different types of vehicles (Arstu Gautam, 2018).

Table 2.1 PCE of truck and bus for specific upgrades

Upgrade (%)	Length (mi)	E_T								
		Percentage 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	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.50-0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.75-1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.00-1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3-4	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50-0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 0.75-1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.00-1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4-5	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.50-0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.75-1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5-6	0.00-0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.30-0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.50-0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 0.75-1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.00-0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.25-0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.30-0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.50-0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 0.75-1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

2.3 Passenger car equivalents

2.3.1 Significance & definition of PCU within several upgrade road condition

Passenger car equivalence (PCE) is a crucial concept in transportation engineering, particularly in the context of several up-grade road conditions. PCE plays a vital role in assessing the performance of roads and highways, especially when considering roadway capacity and traffic operations. It allows for the conversion of different types of vehicles, such as passenger cars, trucks, and buses, into a common unit to simplify traffic flow analysis. By assigning a PCE value to each vehicle type, transportation professionals can effectively evaluate the impact of mixed vehicle types on roadway capacity and congestion levels.

Several studies have contributed to the development of PCE definitions and methodologies specific to upgrade road conditions. Researchers have explored various factors that affect PCE, such as grade steepness, roadway geometry, vehicle characteristics, and driver behavior. These factors influence the performance of different vehicle types on up-grade roads, leading to variations in their PCE values. Understanding the precise definition of PCE under several upgrade conditions is crucial for accurate traffic modeling, capacity analysis, and roadway design.

In a study by (Webster and Elefteriadou 1999), the authors investigated the determination of PCE for several upgrade road conditions based on field observations and empirical data. They highlighted the significance of PCE in assessing traffic operations and capacity, particularly on steep grades. The study proposed a methodology for estimating PCE values specific to upgrade roads, considering the impact of various factors.

(Arstu Gautam, 2018), conducted a comprehensive review of existing literature on PCE under different roadway conditions, including several up-grade roads. Their analysis emphasized the importance of accurately determining PCE values to facilitate efficient traffic operations and ensure proper roadway design. The study provided insights into the definition of PCE under upgrade conditions and highlighted the challenges and considerations involved.

A research article by (Parti, 2021) focused on the development of a PCE model specifically tailored to several upgrade roads. The study integrated advanced modeling techniques and empirical data to establish a comprehensive understanding of PCE variations under different upgrade conditions. The findings highlighted the need for accurate PCE determination to support effective traffic management and infrastructure planning.

Werner et al., n.d. conducted a study to estimate the Passenger Car Unit (PCU) values of recreational vehicles, trucks, and buses at different road gradients. They observed that the PCU increases as the gradient becomes steeper for each vehicle category. (Rilett, Hutchinson, and Whitney 1990) further demonstrated that this influence is particularly pronounced for extra-large multi-axle trucks. (Jain et al. 2020) developed a linear model that depicts the relationship between the gradient and PCU for a specific vehicle category. (Elefteriadou, Torbic, and Webster 1997) found that not only the steepness of the gradient but also the length of the gradient has a significant impact on PCU. For trucks, the PCU increases with both the degree and length of the gradient. (Bains, Ponnu, and Arkatkar 2012) confirmed that this phenomenon also applies to buses, light commercial vehicles, motorized two-wheelers, and three-wheelers, in addition to trucks. Similar results were obtained in other studies (Al-Kaisy et al., n.d.; Giuffrè et al., 2015). (Al-Kaisy et al. n.d.) also observed a consistent increase in PCU for trucks with steeper gradients. However, the length of the gradient only has a significant effect on PCU when the gradient exceeds 2%.

2.62.4 Methodologies for PCU Estimation worldwide

P. Raj, G. Asaithambi, and A. U. R. Shankar conducted various research works by aiming to carried out & overcome the complexities involved in accurate estimation of PCE. Because of the distinct nature of homogeneous and mixed traffic behaviors, they utilized various techniques for assessing passenger car unit values for various facility types such as midblock section, signalized intersection, and uncontrolled intersection.

2.4.1 PCEs Based on Speed

When determining the Passenger Car Equivalence (PCE) based on speed, two commonly used metrics are the mean speed and the 85th percentile speed. Several studies have explored the relationship between these speed metrics and PCE values.

The study by (Chauhan et al. 2021), the authors investigated the determination of PCE for several upgrade road conditions. They utilized field observations and empirical data to estimate PCE values. The study highlighted the significance of considering different speed metrics in the determination of PCE. It provides a measure of the overall speed at which vehicles are traveling on a road segment. It is calculated by averaging the speeds of all vehicles observed. The PCE based on speed considers the collective behavior of vehicles and their impact on traffic flow. The relationship between speed and PCE values can be analyzed to understand the efficiency and performance of different vehicle types.

On the other hand, the 85th percentile speed is a measure of the speed at or below which 85% of the vehicles are traveling. It represents the prevailing speed at which most vehicles are operating. The PCE based on the 85th percentile speed considers the influence of faster-moving vehicles and their effect on traffic conditions. By relating the 85th percentile speed to PCE values, researchers can assess the impact of higher-speed vehicles on overall traffic flow and capacity. (Ahn, 2002) investigated the PCE values for different vehicle types based on the 85th percentile speed. The study collected field data from urban arterial roads and analyzed the relationship between vehicle type, traffic characteristics, and the 85th percentile speed. By considering the 85th percentile speed as a key factor, the authors developed a methodology to estimate PCE values specific to different vehicle types. Therefore, the findings of this study emphasized the importance of using the 85th percentile speed in PCE calculations, as it represents the speed at which most vehicles are traveling. By incorporating this speed metric, the PCE values can accurately reflect the impact of different vehicle types on traffic operations and capacity.

According to (van Aerde and Yagar 1984) PCEs calculation is based on relative speed reduction rates of each vehicle type. They proposed a regression model to estimate the free-speed and the speed reduction coefficients for various percentile speeds.

$$\text{Percentile speed} = \text{free speed} + C1 (\text{number of passenger cars}) + C2 (\text{number of trucks}) + C3 (\text{number of RVs}) + C4 (\text{number of other vehicles}) + C5 (\text{number of opposing vehicles})$$

Coefficients C1 to C5 indicate the relative sizes of speed reductions due to the respective vehicle type or direction of travel. PCE values were determined as

$$\text{PCE for vehicle type } n = \frac{C_n}{C_1} \dots \dots \dots \text{Equation 2.1}$$

Where, C_n=speed reduction coefficient for vehicle type n,

C₁=speed reduction coefficient for passenger cars

(Singh, 2021) as cited by (Raj et al. 2019a) introduced a novel approach to estimate PCU values by considering speed as the key variable. They proposed that the speed of a specific vehicle type accurately reflects its interaction characteristics. Building upon this idea, they formulated the following equation.

$$\text{PCU} = \frac{V_c/V_i}{A_c/A_i} \dots \dots \dots \text{Equation 2.2}$$

Where, V_c =mean speed of the car and V_i =mean speed of vehicle type i

A_c =projected area of the car and A_i =projected area of vehicle type

In a separate study by Thomas et al., a multi-regime speed model was developed to examine the influence of traffic volume and composition on vehicular speed in six-lane divided urban arterials. The researchers assumed linear relationships between speed and classified volumes within each regime to simplify the model development. The study also observed that traffic composition does not significantly affect speed below a certain volume level (<4000 veh/h).

Another study conducted in India revealed that the speed of vehicles varies based on their size and acceleration capabilities, and the Passenger Car Unit (PCU) for a vehicle type increases with wider lane widths. Furthermore, Chandra and Kumar investigated the impact of lane width on PCU values for more than five vehicle types. They introduced the concept of dynamic PCU, which utilizes projected area and speed data to estimate PCUs. The study found that the PCU for a vehicle type increases linearly with the width of the carriageway, although the sensitivity varies among different vehicle types.

2.4.2 PCEs Based on Travel Time

According to (Shalini, 2008) the study focused on determining the Passenger Car Equivalents (PCEs) for heavy vehicles on an urban arterial network. The estimated PCE values were found to be influenced by factors such as traffic volume, vehicle classification, and signal settings. The methodology employed in the study was based on the premise that the reduction in capacity of the network is directly related to the additional delay caused by large vehicles in the traffic stream. PCE, in this context, was measured as the ratio of the total travel times of heavy vehicles to passenger cars traveling through the urban network. This approach allows for a better understanding of the impact of heavy vehicles on traffic operations and provides a quantitative measure to assess their effect on overall network performance. This can be expressed mathematically as

$$PCE = \frac{TT_i}{TT_o} \dots\dots\dots \text{Equation 2.3}$$

Where: TT_i = total travel time of vehicle type i over the network in hours and

TT_o = total travel time of the base vehicle over the network in hours

2.4.3 PCEs Based on Vehicle – Hours

Sumner, R., Hill, D., and Shapiro, S calculate PCE values between consecutive signalized intersections on urban arterial roads using microscopic simulation, NETSIM. The values are derived from the vehicle-hours of road utilization that are added when large vehicles are introduced to the traffic stream.

(P. Saha et al. 2009) conducted a study on urban roads to estimate passenger car equivalents (PCE) using vehicle hour data. They developed a methodology that considered the total hours of different vehicle types and their relative impact on traffic flow to derive PCE values, reflecting the equivalent contribution of each vehicle type to the overall traffic volume. Data were collected from through lanes at various signalized intersections in Dhaka Metropolitan City, Bangladesh, based on specific criteria such as high traffic volumes, significant queuing, and lane restrictions. Different vehicle types, including cars, auto-rickshaws, minibuses, and buses, were included in the data collection. The headway ratio method was employed to estimate PCE values for each vehicle type by analyzing the inter-vehicle time headways. The computed PCE values for auto-rickshaws have a slight difference when it compared to MOC, 2016

$$e_x = \frac{h_A(x_x)}{h_A(c_c)} \dots\dots\dots \text{Equation 2.4}$$

Where, $h_A(c_c) = U - \frac{C}{\text{No.of headways car following car}}$

$$h_A(x_x) = U - \frac{C}{\text{No.of headways vehicle type X following vehicle type X}}$$

$$C = \frac{abcd(w - x - y - z)}{abc + abd + acd + bcd}$$

e_x = Passenger Car Equivalence $h_A(c_c)$ = Adjusted mean headways for car following car; $h_A(x_x)$ = Adjusted mean headways for vehicle type x following vehicle type x

$h_A(x_c)$ = Average headway of a type x vehicle followed by a car; $h_A(c_x)$ = Average headway of a car followed by a type x vehicle; U = Uncorrected mean headway; and C = Correction factor

a = Number of headways for car following car; b = Number of headways for car following type x vehicle; c = Number of headways for type x vehicle following car; d = Number of headways for type x vehicle following type x vehicle.

w = Mean headways for car following car; x = Mean headways for car following type x vehicle; y = Mean headways for type x vehicle following car; and z = Mean headways for type x vehicle following type x vehicle.

2.4.4 PCEs Based on Chandra’s method

In the study conducted by (Anon n.d.) the focus was on estimating the capacity of the road and determining the passenger car units (PCUs) for different vehicles under heterogeneous traffic conditions. The data collection process involved using video recorders on five main highways in Khandwa city. Traffic volume and speed data were extracted at five-minute intervals, covering both peak and non-peak periods. The study aimed to compare PCU values and assess the reliability and realism of different methods. It was found that Chandra's method provided more reliable and realistic results compared to other approaches. The PCU for each vehicle type was calculated using Equation 2, for Chandra’s method and equation 5 for density method.

$$PCU = \left(\frac{Density}{Density_{ref}} \right) * PCU_{ref} \dots\dots\dots \text{Equation 2.5}$$

Where, PCU: Passenger Car Unit, Density: Traffic density or vehicle density

Density_{ref}: Reference density (typically the density of passenger cars)

PCU_{ref}: Reference PCU value (typically the PCU value of passenger cars)

The significance of determining PCUs lies in the need to convert the mixed traffic into a homogeneous unit, which is referred to as passenger car equivalence. This allows for a common unit of measurement that can be used to analyze and assess traffic conditions and capacity. These methodologies provide a means to quantify the passenger car equivalent of different vehicle types based on their characteristics and impact on traffic flow.

Chandra’s method for estimating passenger car units (PCU) is that it considers both the speed and projected area of vehicles. However, in congested traffic conditions where the speeds of different vehicle types are similar, the PCU value estimated by this method is primarily influenced by the ratio of their areas. To address this limitation, a more logical and accurate approach proposed by (Sharma and Biswas 2021a) suggests considering the "influence area" instead of the "projected rectangular area" for PCU

estimation. By incorporating the concept of influence area, the estimation of PCU becomes more reliable and reflective of the actual traffic conditions.

2.4.5 PCEs Based on Simulation Model development.

(Webster and Elefteriadou 1999) conducted a simulation study to analyze the Passenger Car Units (PCUs) of trucks on basic freeway sections. In their study, the independent variables included vehicle speed, flow rate, and occupancy, which were used to determine the dependent variable, PCUs. They utilized a microscopic simulation model to simulate traffic flow and measure the performance of trucks. The formula they used to estimate the PCUs of trucks considered the values of these variables and compared them to the PCUs of passenger cars. This research provided valuable insights into the capacity and performance of trucks in relation to passenger cars on freeway sections.

The study also conducted by (Mehtar, Chandra, and Velmurugan 2014) aimed to analyze the impact of traffic volume and composition on Passenger Car Unit (PCU) values on four-lane and six-lane divided highways. The independent variables included traffic volume, vehicle type composition, and Levels of Service (LOS) for different highway configurations. Using the VISSIM microscopic simulation model, the researchers calibrated important parameters such as CC0, CC1, and CC2 (CC0 represents the stopping distance (m) between the vehicles and CC1 is the minimum time headway (s) that the vehicles are desired to maintain at higher volume level, CC2 is the variation in safety distance between the vehicles in car-following condition) to match the field capacity values. They derived PCU values using the formula stated in equation 2 for different vehicle categories commonly found on interurban highways in India. The study demonstrated that PCU values varied with traffic volume and the proportional share of each vehicle type in the traffic stream. The accuracy of the PCU values was verified by comparing the simulated speed-flow curves with those derived from field data, indicating their reliability in converting mixed traffic flow into equivalent PCU numbers. The research findings provide valuable insights for understanding the relationship between traffic volume, composition, and PCU values, and offer a methodology that can be adapted for similar studies in different traffic conditions (Mehtar, Chandra, & Velmurugan, 2014).

(Mehtar et al. 2014) also draw a dashed line curve which represents the relationship between speed and density based on Greenshield's linear model. Since measuring density directly in the field is challenging, the researchers calculated using speed and volume data. The capacity of a four-lane divided highway is estimated as 4,950 PCU/h, while the capacity of a six-lane divided highway is estimated as 6,700 PCU/h in each direction of traffic. The capacity of a highway is influenced by various factors, including the

composition of the traffic stream. To examine the impact of traffic composition on capacity, the microscopic traffic simulation model VISSIM was used to generate speed-flow curves for different combinations of traffic composition.

In relation to this, the simulation technique is a valuable tool for analyzing various traffic conditions and controlling traffic and geometric factors. However, its successful implementation requires a deep understanding of traffic simulation and the availability of diverse real-world data that accurately represents different traffic and geometric scenarios. Validating the simulation model can be challenging but is crucial to ensure its reliability and accuracy (Sharma & Biswas, 2021)

2.4.6 PCEs Based on Multiple Linear Regression Method

This analysis method is used in many studies to derive PCEs. (Raj et al. 2019) incorporated following equation for estimation of PCE, which is given in equation.

$$S = FFS + a_1. PC + a_2. Bus + a_3. MC + a_4. HV$$

Where: S= Avg. traffic stream speed, FFS= Free flow speed, PC= No. of Passenger Cars in traffic stream, Bus= No. of Bus in traffic stream, MC= No. of Motorcycle in the traffic stream, HV= No. of Heavy vehicle in the traffic stream, a₁, a₂, a₃, a₄ = Marginal effect of respective mode on Avg. traffic stream speed.

Based on the estimation of the above co-efficient in the equation, PCE factors for different type of vehicle are derived by taking the ratio of co-efficient obtained for a particular vehicle type with the co-efficient obtained for the reference vehicle (i.e., passenger car). This is given using the following equation:

$$PCE = \frac{a_{ir}}{a_1} \dots \dots \dots \text{Equation 2.6}$$

The method based on multiple regression analysis is criticized in the literature based on the argument that speed is usually not a linear function of volume. However, the method can be utilized for a range of speed where it is behaving linearly with the volume.

According to (Raj et al. 2019), the speed model was used to study the variation of PCE with base volume and composition. The effect of traffic volume and its composition on PCU of different vehicle types in a mixed traffic stream was investigated by taking an urban divided midblock section as the case study. Determined dynamic PCU values by expressing the speed-flow relationship in the form of multiple

regression equation taking the speed of cars as the dependent variable and volume of different vehicle categories as the independent variables. The ratio of the regression coefficients of different vehicle categories to the regression coefficient of the car gives an estimate of PCU factors. The speed of car was regressed against the volumes of different vehicle types as follows:

$$V_1 = A_0 + A_1Q_1 + A_2Q_2 + A_3Q_3 + \dots + A_nQ_n$$

Where V_1 = speed of cars; Q_1 = flow of cars; Q_2, Q_3, \dots, Q_n = flow of vehicle type 2, 3, ..., n; A_1, A_2, \dots, A_n = regression coefficients; and A_0 = constant. Dynamic PCU of vehicle type n is given by:

$$DPCU = \frac{A_n}{A_1} \dots \dots \dots \text{Equation 2.7}$$

It is compatible with the highly heterogeneous traffic but sometimes, regression coefficients come out to be negative which yields inaccurate estimation of PCU.

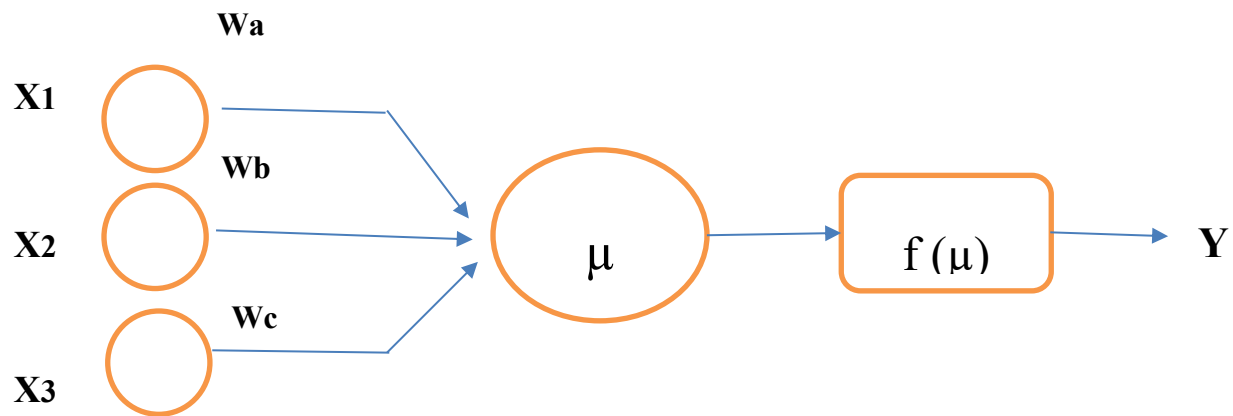
2.4.7 PCEs Based on Artificial neural network

Artificial Neural Networks (ANN) are mathematical algorithms designed to learn and process information like the functioning of the human brain. These models are developed empirically and provide accurate solutions to complex problems that are difficult to solve using conventional techniques. They are particularly useful for addressing challenges that can only be understood through field observations (Webster and Elefteriadou 1999).

ANNs simulate the simplified methods of the human brain and can replace traditional computations for solving challenging problems. They acquire knowledge through learning, like how the human brain learns from examples. ANN has been widely used in various engineering applications due to its ability to handle real-valued, discrete-valued, and vector-valued functions (Biswas et al. 2016; Biswas, Chandra, and Ghosh 2017).

Model of a Neuron

Artificial Neural Networks (ANNs) are conceptualized as mathematical abstractions of neural biology, built on the principles that information processing takes place at multiple interconnected neurons, with signals transmitted between them through weighted connections, and each neuron applying an activation function to its input for output signal determination.



Input units **Connection weights** **summing function** **computation** **output**

A neural network is made up of many small processing units called neurons, which are also sometimes referred to as units, cells, or nodes.

Activation function

It is a function that determines the output of the neural network. Activation functions in neural networks come in various types: Identity Activation simply returns the input as output, Binary Step Activation yields binary results (0 or 1) based on a threshold, Bipolar Step Activation assigns -1 or 1, Sigmoidal Activation creates an S-shaped curve outputting values between 0 and 1 (or -1 and 1 for bipolar sigmoid), Hyperbolic Activation exhibits an S-shaped curve with a range of -1 to 1, and ReLu (Rectified Linear Unit) Activation introduces non-linearity by returning positive input values as-is and converting negative ones to 0, making it a popular choice in deep learning models (Nair & Hinton, 2010).

Characterization ANN

- **Architecture (Interconnections):** The architecture of an ANN refers to the pattern of connections between neurons. There are several types of architectures commonly used: Feed Forward when information flows in one direction, from the input layer to the output layer, without any loops or cycles. This type of architecture is widely used in various applications, Feedback architectures include connections that allow information to flow backward, enabling the network to use previous outputs as inputs in subsequent iterations (Rumelhart, Hinton, and Williams 1986), Recurrent architectures have recurrent connections that allow loops or cycles in the network, enabling it to have dynamic temporal behavior and memory (Hochreiter and Schmidhuber 1997).

- **Strategy / Learning Algorithm:** it is a critical aspect of neural network operation determining weight adjustments, encompasses various strategies including supervised learning, which minimizes the disparity between actual and desired outputs (Bishop 2006); unsupervised learning, focused on identifying data patterns without explicit target outputs (Bishop 2006); and reinforcement learning, where weights are adapted to maximize cumulative rewards from interactions with an environment (Sutton and Barto 1998).
- **Activation Function:** The activation function determines the output of a neuron based on its input as discussed above.

Layers of ANN

In a neural network architecture, the input layer receives and encodes input data, acting as an interface between external data and the network, while hidden layers, positioned between the input and output layers, are responsible for learning complex patterns and extracting meaningful representations, with the output layer providing final predictions or outputs based on the nature of the task (Goodfellow, 2016).

In practice, data is fed into specialized software such as Alyuda Neuro Intelligence, which performs various operations to prepare the data for analysis. The software automatically divides the data into training samples (70%), testing samples (15%), and verification samples (15%) to ensure robust model evaluation. Additionally, the software preprocesses the data by scaling it within specific ranges for the input and output layers of the neural network. This preprocessing step is essential for optimal data representation and effective model training.(Srikanth and Mehar 2018)

Once the data is preprocessed, the software generates a neural network framework and selects the most suitable training algorithm based on the minimum absolute error criterion. The training simulations are then conducted using the chosen algorithm until the desired convergence effect and highest accuracy are achieved. The network model is evaluated by comparing the predicted data with the actual input data during the verification step. This evaluation assesses the accuracy of the network's predictions and validates its performance.(Biswas et al. 2016; Biswas, Chandra, et al. 2017)

The approach described above, as highlighted by (Khademi et al. 2017), demonstrates the utilization of advanced algorithms and training simulations in artificial neural network models. These models serve as powerful tools for solving complex problems and achieving high levels of accuracy in prediction tasks.

Research which determines PCU using ANN

Alyuda NeuroIntelligence (Version 2.2) was utilized to develop an Artificial Neural Network (ANN) model for estimating Passenger Car Unit (PCU) values. The model employed the Levenberg-Marquardt training algorithm with local minima avoidance. The network architecture consisted of four inputs representing the width of the pavement, shoulder condition, directional split, and the percentage of slow-moving vehicles. The output of the network was the PCU value for buses. To validate the model, the obtained results were compared with those reported by different researchers who investigated the impact of various affecting parameters. The comparison revealed a high degree of correlation between the predicted PCU values from the ANN model and the quoted results. This suggests that the ANN model can effectively capture the relationship between the input factors and the PCU values, yielding reliable estimations (Khademi et al. 2017).

Biswas, Chandra, et al. (2017) used Artificial Neural Networks (ANN) to predict traffic speed and Passenger Car Equivalent (PCE) on urban roads, emphasizing the strong influence of traffic volume and composition on both speed and PCE, particularly for larger vehicles. Their ANN model showed superior accuracy in speed prediction, highlighting its potential for urban planning and traffic management strategies. The accuracy of the model was assessed using three conventional parameters: root-mean-square error (RMSE), mean absolute percentage error (MAPE), and relative root-mean-square error (RRMSE).

$$\begin{aligned}
 RMSE &= \sqrt{\frac{\sum_{i=1}^n (Z_i' - Z_i)^2}{n}} \\
 MAPE &= \frac{100}{n} \sum_{i=1}^n \left| \frac{Z_i' - Z_i}{Z_i'} \right| \\
 RRMSE &= \sqrt{\frac{\sum_{i=1}^n (Z_i' - Z_i)}{\sum_{i=1}^n (Z_i')^2}}
 \end{aligned}$$

.....Equation 2.8

Where, Z_i' and Z_i are the actual and the predicted value of variable Z at i^{th} observation.

n is the total number of observations.

➤ **Literature focus and limitations**

The study of (van Aerde and Yagar 1984) focuses specifically on PCE calculation for two-lane rural highways, providing insights into the relative speed reduction rates of different vehicle types. The

proposed regression model offers a systematic approach for estimating PCE values. But the study's scope is limited to rural highways and does not consider factors such as traffic volume or lane width.

The study of (Thomas, Srinivasan, and Arasan 2012) investigates the effects of traffic volume and composition on vehicular speed in urban arterials, offering insights into real-world traffic conditions. The multi-regime speed model provides a framework for understanding speed variations. But the study does not specifically address PCE calculation or the impact of vehicle type on speed.

The study of (Meher et al. 2014) in India explores the variation in speed among different vehicle types based on their size and acceleration capabilities. The concept of dynamic PCU provides a new approach for estimating PCU values. However, the study's findings are specific to the Indian context and may not be directly applicable to other regions.

(Chandra and Kumar 2003) study examines the impact of lane width on PCU values for multiple vehicle types, providing a more comprehensive understanding of the relationship between lane width and PCU. But study focuses solely on the impact of lane width on PCU values and does not consider other external factors that may influence PCU, such as road surface conditions, grade, or driver behavior. Considering these additional factors could provide a more comprehensive understanding of PCU determination.

(P. Saha et al. 2009), investigated the PCE based on vehicle hours provides insights into the capacity and flow characteristics of different vehicle types compared to passenger cars. It considers the duration of vehicle presence on the road network and captures the relative impact of different vehicle types on traffic congestion and overall network performance. The accuracy of PCE estimates depends on the quality and reliability of vehicle hour data, which may vary depending on data collection methods and sources. Additionally, the methodology used to calculate PCE values based on vehicle hours may vary across studies, and it is essential to consider the specific approaches such as weighting factors, time-driven analysis, data collection techniques.

2.7 Methods of PCU Estimation under local studies

(Anon., n.d.) calculates the Passenger Car Equivalent (PCE) on the Addis Ababa - Adama expressway using a flow density model, revealing that as the percentage of trucks and buses decreases from 10% to 50%, the PCE increases; the study determines PCE ranges between 1.4 and 7.8 for a 5% improvement in road upgrade when the bus to truck ratio is 10% to 50%, and between 5.6 and 7.8 for a 5% enhancement

in road quality with a 10% bus to truck ratio, surpassing the recommended factor in the Highway Capacity Manual (HCM) of 1.5 to 3.0.

(Tullu & Quezon, 2020), determine Passenger car unit values based on volume and carriage way width along four and six lane roadway roads of Addis Ababa using multiple regression method. This study shows that PCU increases when traffic volume increases to the effect that the speed of larger vehicles decreases, but the speeds of smaller vehicles are not affected. The study also shows PCU increases as carriageway width increases. This is due to the case of wider carriageways; all vehicles travel within normal or maximum speed since the road is wider.

According to the study conducted by (Amare, 2019) along Addis Ababa on signalized intersection, the mean local PCEs of Small Busses are 1.49, 1.50, and 1.68 on first (inner), second (middle), and third (outer) lanes respectively. Similarly, the mean local PCEs of Large Busses are 1.95, 2.19, and 1.99 on first (inner), second (middle), and third (outer) lanes respectively. Trucks on the other hand have mean local PCE values of 1.62, 1.55, and 1.44 on first (inner), second (middle), and third (outer) lanes respectively. Whereas, Truck Trailers have larger mean local PCE values which are 3.62 and 3.78 on second (middle) and third (outer) lanes respectively. The results indicate that PCEs in middle lane are somehow larger than PCEs in first (inner) and third (outer) lanes for Small Buses and Large Buses. Trucks on the other side have the largest PCE values on the first (inner) lane while, Truck Trailers exhibit the largest PCEs on third (outer) lane.

(Bekele n.d.), study the capacity and PCU estimation under heterogeneous traffic on trunk road of Ethiopia. The study tried to compare PCE values using three different models: Chandra's method, VISSIM simulation mode and homogenization coefficient method. And the result showed that value of PCU was decreasing as the volume of the road sections increased for all vehicles, except for three wheelers. The PCU resulted by Chandra's method for 4WD, bus, truck and three-wheeler are (1.43, 3.96, 4.63 and 0.64) were greater than the PCU value resulted by Homogenization coefficient methods (1.27, 2.7, 3.13, 0.85) respectively for all types of vehicles, except for three wheelers.

According to the study conducted by (Tadiyos Marie, 2021) the study focused on estimating the Passenger Car Equivalence (PCE) values for mid-block sections in Addis Ababa using an Artificial Neural Network (ANN) model. The analysis revealed that increasing traffic volume resulted in a decrease in speed for all vehicle types, while the PCE values showed varying trends. Changing the proportion of vehicle types had a pronounced effect on traffic speed and PCE, particularly for buses and trucks. The study provided

valuable insights into the relationship between traffic characteristics, vehicle composition, speed, and PCE values, contributing to a better understanding of road capacity and performance in the context of Addis Ababa's mid-block sections.

The MATLAB-developed model divides datasets into three parts: 70% for training and 15% each for testing and validation. Results indicate that increasing traffic volume from 300 to 2400 vehicles per hour lowers speeds across vehicle types, reducing PCE values for most types except minibus, with a more noticeable impact on bus and truck speeds.

➤ Literature focus and limitations

The study by (Tamene, 2016) provides insights into PCE estimation using a flow density model and highlights the influence of truck and bus proportions on PCE values. The study also determined varying PCE values ranging from 1.4 to 7.8 for a 5% upgrade in road gradient for a 10% to 50% bus to truck proportion. However, these values exceed the recommended factors in the Highway Capacity Manual (HCM), which suggests PCE values of 1.5 to 3.0. Therefore, the study's findings regarding PCE values exceeding the recommended factors in the Highway Capacity Manual (HCM) need further validation and verification.

(Tullu & Quezon, 2020) explores the impact of traffic volume and carriageway width on PCU values, contributing to a better understanding of road capacity along four and six-lane roads in Addis Ababa. They used the multiple regression method and found that PCU increases with increasing traffic volume, leading to decreased speeds for larger vehicles but no significant effect on smaller vehicles. The study also observed that PCU increases with wider carriageway widths, as wider roads allow all vehicles to travel at normal or maximum speeds. However, it's important to note that the study's findings are specific to the studied roads in Addis Ababa and may not be applicable to roads with different characteristics or locations. Additionally, the multiple regression method used in the study assumes a linear relationship between factors, which may not capture all the complexities influencing PCU accurately since the suggests a potential non-linear relationship between factors affecting PCU values, such as traffic volume and carriageway width.

(Amare, 2019) looked at how different types of vehicles affect road capacity at signalized intersections in Addis Ababa. The study discovered that small buses, large buses, trucks, and truck trailers had different impacts in various lanes. Buses showed higher impact in the middle lanes, while trucks and trailers had more impact on the first and outer lanes, respectively. However, these findings might only apply to

intersections in Addis Ababa and may not reflect PCU values on other roads due to local factors at these specific intersections.

(Bekele n.d.) study compares different PCE estimation methods and highlights the impact of road volume on PCE values. In a study comparing PCE values using three different models (Chandra's method, VISSIM simulation, and homogenization coefficient method), (Bekele n.d.) found that the PCE values resulting from Chandra's method were generally higher than those from the homogenization coefficient method, except for three-wheelers. The study also observed a decreasing trend in PCE values as the volume of road sections increased for most vehicles. Since the study compared PCE values using different estimation methods, the selection of specific methods and the generalization of findings to other road types or regions may introduce limitations. And the study's focus on trunk roads in Ethiopia may limit the generalizability of the findings to other types of roads or countries.

(Tadiyos Marie, 2021) study utilizes an ANN model to estimate PCE values and analyzes the relationship between traffic characteristics, vehicle composition, speed, and PCE value for mid-block sections in Addis Ababa. The study found that increasing traffic volume led to decreased speeds for all vehicle types, while PCE values exhibited varying trends. Changing the proportion of vehicle types had a significant impact on traffic speed and PCE, particularly for buses and trucks. As the study focused on mid-block sections in Addis Ababa, the findings may not be representative of PCU values in other road sections or areas. The use of an Artificial Neural Network (ANN) model introduces dependencies on the model's accuracy and the quality of the input data used for training and validation.

2.8 Summary

Table 2.2 Advantages and disadvantages of the methods used to determine PCU

Method	Advantages	Disadvantages
PCEs Based on Speed	<ul style="list-style-type: none"> • Simple and easy to calculate using speed data. • Widely used in practice • Known for its simplicity and ability to capture the dynamic nature of PCU. • Suitable for analyzing mixed traffic streams consisting of various vehicle 	<ul style="list-style-type: none"> • May not capture the full range of vehicle characteristics and traffic conditions. • The concept of 'influence area' instead of 'projected rectangular area' would be more logical and accurate in estimating PCU (Kumar et al. 2018). • Does not account for other factors affecting capacity, such as vehicle size or

	categories(Biswas, Chandra, et al. 2017).	<p>road geometry.</p> <ul style="list-style-type: none"> Assumes a linear relationship between speed and PCE, which may not always hold true (Al-Kaisy et al. n.d.).
PCEs Based on Travel Time	<ul style="list-style-type: none"> Shows how different vehicle types affect travel time. Considers the actual time it takes for a vehicle to travel a specific distance, including factors like delays and congestion. 	<ul style="list-style-type: none"> It needs accurate and dependable travel time data. Getting precise travel time measurements can be difficult. It might not consider all the factors that affect PCE (Giuffrè et al. 2015).
PCEs Based on Vehicle – Hours	<ul style="list-style-type: none"> Considers the occupancy factor of different vehicle types. Incorporates the number of vehicles and their duration of travel, providing a measure of total vehicle impact. 	<ul style="list-style-type: none"> Relies on accurate and reliable data on vehicle occupancy. Does not consider the variations in vehicle types or their different capacities. This may not accurately represent their actual impact on traffic flow (Giuffrè et al. 2015).
PCEs Based on Chandra’s method	<ul style="list-style-type: none"> Incorporates the concept of interaction between vehicle types based on speed. Utilizes a regression-based approach to estimate PCE, considering multiple variables. 	<ul style="list-style-type: none"> May not capture all factors influencing PCE accurately. Relies on the availability and quality of data for calibration. May not capture all relevant factors affecting PCE accurately.(Mehar et al. 2014)

<p>PCEs Based on Simulation Model</p>	<ul style="list-style-type: none"> • Allows for more detailed modeling and consideration of various factors influencing PCE. • Allows for detailed modeling and analysis of complex traffic conditions, capturing various factors affecting PCE. • The PCU estimation using this method is considered more accurate compared to the multiple linear regression method (Srikanth and Mehar 2017). 	<ul style="list-style-type: none"> • Requires sophisticated simulation models and input data. • Requires significant effort and resources to develop and calibrate the simulation model. Sensitivity to model assumptions and input parameters (Al-Kaisy et al., n.d.). • The calculation process involved in this method can be lengthy and tedious due to the need for iteration (Biswas, Chakraborty, et al., 2017).
<p>PCEs Based on Multiple Linear Regression</p>	<ul style="list-style-type: none"> • Allows for statistical analysis and identification of significant variables. • Allows for the incorporation of multiple variables and their interactions, providing a statistical approach to estimating PCE. 	<ul style="list-style-type: none"> • Assumes a linear relationship between input factors and PCE, which may not hold in all cases. • Assumes a linear relationship between input variables and PCE, which may not accurately capture non-linear relationships. Relies on the availability of high-quality data for model calibration.(Giuffrè et al. 2015) • In some cases, the regression coefficients obtained in this method may be negative, leading to inaccurate estimation of PCU (van Aerde and Yagar 1984).

<p>PCEs Based on Artificial Neural Network</p>	<ul style="list-style-type: none"> • Can capture complex relationships and non-linear interactions between variables, providing more accurate predictions of PCE. • Ability to learn and adapt from large datasets, allowing for improved model performance and better estimation of PCU values. (Biswas, Chandra, et al., 2017). • Ability to generalize well to unseen data, making ANN models suitable for different traffic scenarios and locations. (Aggarwal, K.K., Singh, Y., Chandra, P., & Puri GGS, M. (2005) • Can incorporate additional factors and variables beyond traditional methods, leading to a more comprehensive understanding of PCE estimation 	<ul style="list-style-type: none"> • Requires a large amount of training data and computational resources. • Requires careful training and validation to ensure accurate predictions. May be computationally intensive and require expertise in ANN modeling.(Giuffrè et al. 2015).
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Based on the literature reviews provided earlier and the data presented in Table 2.2, this research selected Equation 2.2 as a method for calculating PCU with a focus on speed as a vital factor. Multiple regression was selected as the chosen method to develop a mathematical model. Additionally, an Artificial Neural Network (ANN) model was chosen for predicting vehicle speeds, given its ability to capture complex relationships and non-linear interactions among variables.

3. RESEARCH METHODOLOGY

3.1 Introduction

This chapter focuses on several key aspects related to the study as shown in the Figure below.

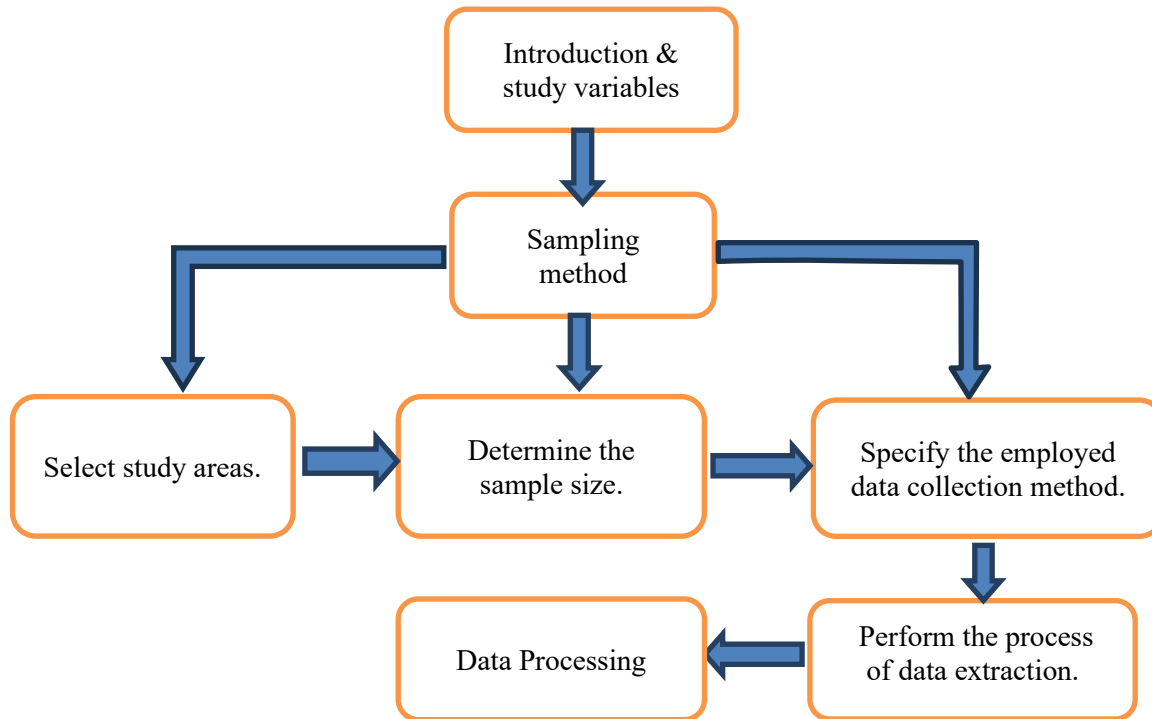


Fig 3.1 flow chart of Methodology for the research

3.2 Study variables

In this research, both dependent and independent variables are considered.

3.2.1 Dependent variable

The research's dependent variable is Passenger Car Equivalence (PCE) values.

3.2.2 Independent Variable

In this research, independent variables could include:

- Traffic volume/ Number of vehicles:

This variable refers to the count of vehicles passing through a specific section of road within a given time. It helps in understanding the flow and density of vehicles on the road.

- Composition of vehicle

This variable involves determining the percentage of different types of vehicles present within the specified stretch. It provides insights into the mix of vehicle types and their contribution to overall traffic.

- Length and width of different vehicle

This variable represents the standard dimensions of vehicles, including their length and width, as provided by the respective manufacturers. It helps in assessing the physical characteristics of vehicles.

- Travel time

This variable measures the time taken by vehicles to travel across the designated stretch. It is an important factor in understanding the efficiency and performance of the road.

- Number of Lane

It is the perpendicular dimension of a road along the specified stretch. It helps in evaluating the road capacity and traffic management.

- Road gradient

This variable indicates the percentage of incline or decline along the given stretch of road.

- Speed of vehicles

This variable represents the distance covered by a vehicle in a unit of time. Vehicle speed is a critical factor that affects safety, travel time, comfort, convenience, and overall transportation efficiency.

3.3 Data Collection/sampling Techniques

Sampling/ Data collection is the process of selecting and measuring the study variables in a systematic way to answer the stated research question and assess the outcome. There are two types of sampling methods: Probability sampling involves a random selection process, ensuring that every individual or element in the population has an equal chance of being included in the sample and non-probability sampling involves the non-random selection of individuals or elements based on convenience, accessibility, or specific criteria. In this research, both probability & nonprobability sampling methods are used. By employing these methods, the research aims to obtain reliable and statistically valid data that can

be used to draw meaningful conclusions and make inferences about the broader population.(Singh and Masuku n.d.)

Then, among many probabilities & nonprobability data collection technics this research used:

- Random sampling

A type of sampling in which each vehicle in the population has an equal probability of being selected. The sample size can be determined based on the desired level of precision and confidence. In this study, the sample size was determined using this sampling technique. Employing random sampling for sample size determination is essential for avoiding selection bias and ensuring a fair representation of the data, thereby enhancing the reliability and applicability of the study results.

- Purposive or judgmental sampling

It is a type of non-probability sampling method and a form of non-random sampling method where researchers deliberately choose specific individuals, groups, or elements from a population based on their judgment, expertise, or specific criteria. The sampling method used in the study involved selecting specific areas based on a combination of on-site observation and distinctive features associated with those areas. This indicates that the chosen areas are characterized by uphill roads and exhibit a proportionate level of vehicle movement.

3.4 Study area

The areas selected for this research follow the purposive or judgmental sampling method. Four specific sections or study areas are chosen for the study. These study areas are found in the entrance & exit of Addis Ababa, characterized by uphill road geometry. In choosing uphill areas at the entrance and exit of the city for study, the study's primary objective is to conduct a comprehensive analysis of traffic dynamics, particularly focusing on the proportional movement of vehicles from small to heavy types. These specific areas, being strategic points for entering and exiting the city, are essential for understanding the encounters posed by uphill gradients. This choice is driven by the need to determine Passenger Car Equivalent (PCE) values, which play a crucial role in assessing the impact of different vehicle types on intra-urban roads. By strategically selecting these areas, the research aims to capture the nuances of traffic flow, including the behavior of medium to heavy trucks, and quantify their impact on the road network.

The reason behind focusing on entrance and exit points lies in their significance as major transportation hubs within the city. These areas are vital for commuters, trade, and logistics, making them representative of intra-urban traffic conditions. The uphill roads at these locations are particularly due to their challenging which can significantly influence the movement of vehicles. This includes not only the uphill gradients but also the lowness of the posted speed limits in these areas, further categorizing them under intra-urban roads. Understanding the proportional movement of vehicles on these intra-urban uphill roads, impacted by both challenging terrain and speed restrictions, is essential for determining accurate Passenger Car Equivalent (PCE) values. This comprehensive analysis will contribute to better-informed decisions regarding the capacity and efficiency of the city's transportation infrastructure.

In summary, the study aims to bridge the gap between the presence of uphill roads at city entrance and exit points, the proportional movement of vehicles, and the determination of PCE values. By focusing on these intra-urban areas, the research tries to provide insights into the specific problem posed by uphill gradients within the city, offering valuable information for urban planners and policymakers to enhance the capacity and functionality of the local transportation network.

3.4.1 Specific study area locations

Study area one: the road from Gojam ber to Entoto road. The selected area starts 400m far from Gojam ber Ring Road to Entoto side and ends at 1.2km from Gojam ber to Northern exiting side of Addis Ababa, Entoto. This section is located on the Northwestern part of Addis Ababa. The road is a one way one lane road in each direction with high traffic flow during peak hours and mainly serves passenger car, bus & large truck that enter & exit from the city, Addis Ababa. The traffic data recorded is on the main uphill road line from Gojam ber to entoto direction.



Fig 3.2 Start point of the study, Gojam ber



Fig 3.3 Representative picture of End point of the study, Entoto

Study area Two: the road from 18 mazoriya to New Ambo Road. The selected area starts at 1.5km far from kolfe ring road (18 mazoriya) Western exiting side of Addis Ababa, Ambo Road and ends at 0.5km from (kolfe ring road)18 mazoriya. This section is in the western part of Addis Ababa. The road is a one way one lane road in each direction with high traffic flow during peak hours and mainly serves passenger car, bus & large truck that enter & exit from the city, Addis Ababa. The traffic data recorded is on the main upgrade road line from New Ambo Road direction to 18 mazoriya.





Fig 3.4 Start point of the study, New Ambo Road



Fig 3.5 Representative picture of End point of the study, 18 mazoriya

Study area Three: the road from Abem to Kotebe Kara. The selected area starts 400m far from Abem on the road from Megenaga – wesen – kotebe kara road and ends at kotebe kara, near to Northern exiting side of Addis Ababa, Tafo. This section is in the Northeastern part of Addis Ababa. The road is a two-way

three lane road in each direction with high traffic flow during peak hours and mainly serves passenger car, bus & large truck that enter & exit from the city, Addis Ababa. The traffic data recorded is on the main upgrade road line from Abem to Kotebe Kara direction.

	
<p>Fig 3.6 Start point of the study, Abem</p>	<p>Fig 3.7 Representative picture of End point of the study, Kotebe kara</p>

Study area Four: the road from Goro to Jacros. The selected area starts 150m far from Goro on the road from Megenaga –mebrathaile – Goro road, near to Southern & eastern exiting side of Addis Ababa, tuludimtu and ends at Jacros, 1.5km from Goro. This section is in the Southeastern part of Addis Ababa. The road is a two-way three lane road with high traffic flow during peak hours and mainly serves passenger cars, buses & large trucks that enter & exit from the city, Addis Ababa. The traffic data recorded is on the main upgrade road line from Goro to Jacros direction.



Fig 3.8 Start point of the study, Goro around goro bridge



Fig 3.9 Representative picture of End point of the study, Jacros near to intersection.

Table 3.1 Summary of road segments selected for this study.

Road segment	Number of lanes (one Directional)	Percent of Upgrade	Station	Starting Coordinate		Ending Coordinate	
				X	Y	X	Y
Gojam ber – Entoto	one	4.04%	0+000 - 0+600	470977.001	1002404.8	471141.969	1002766
		7.45%	0+600 - 1+000	471141.969	1002766.3	470980.7	1003089
		2.92%	1+000 - 1+200	470980.7	1003089.1	470833.671	1003184
18 mazoriya – new ambo road	one	5.95%	0+000 - 0+400	467164.372	998418.83	467451.712	998406
		7.34%	0+400 - 0+620	467451.712	998406.13	467763.413	998343
		5.88%	0+620 - 1+000	467763.413	998343.21	468143.197	998350
Abem – kotebe kara	Three	10.28%	0+000 - 0+240	484244.133	998722.621	484479.144	998800
		7.68%	0+240 - 0+740	484479.144	998800.334	484920.878	999029
Goro – Jacros	Three	8.69%	0+000 - 0+102	480527.000	994593.000	480425.000	994697
		8.18%	0+102 - 0+203	480425.000	994697.000	480324.000	994797
		6.36%	0+203 - 0+311	480324.000	994797.000	480216.000	994900
		5.45%	0+311 - 0+407	480216.000	994900.000	480110.000	995008
		3.64%	0+407 - 0+507	480110.000	995008.000	480010.000	995101

3.4.2 Choosing Study Areas for Research: Specific Criteria and Selection Process

The study areas mentioned above were carefully selected based on specific criteria, taking into consideration their suitability for addressing the research objectives. These criteria helped ensure that the chosen areas met the necessary requirements for the study. These criteria include the following.

- Presence of a diverse traffic mix during peak hours: The selected areas should experience a variety of vehicle types and traffic volumes, providing a representative sample for the study.
- Minimal influence from parking and pedestrian crossing: The areas are selected in locations where the impact of parking and pedestrian activities on traffic flow is minimal, allowing for a clearer analysis of the traffic conditions.
- Absence of cross traffic: To focus on the selected areas' traffic characteristics, it is important that they are relatively free from cross-traffic, reducing potential interference with the study observations.
- Lack of street vendors and nearby establishments: The areas chosen are away from street vendors and various establishments such as schools, hospitals, churches, and markets. This helps minimize potential disruptions and influences on traffic flow patterns.
- Avoidance of animal crossings: The selected areas are free from animal crossings to ensure that traffic flow is not affected by such factors.
- Proximity to major radial routes entering or exiting Addis Ababa: The study areas are located near key radial routes that serve as major entry or exit points to/from the city of Addis Ababa. This ensures that the selected areas are representative of traffic patterns along important transportation corridors.

Furthermore, the selected areas specifically focus on sections of roads that have uphill roads, ensuring that the data collected reflects the minimum operating speed of vehicles in these conditions. By excluding roads with speed humps, the research can obtain more accurate and representative data when calculating vehicle speeds.

Moreover, the inclusion of heavy vehicles in the study is crucial due to their distinct characteristics compared to cars. Heavy vehicles tend to be larger, slower, and have lower acceleration capabilities, requiring more space on the road and operating at slower speeds, especially on grades. These factors significantly impact traffic flow and have implications for determining the equivalent passenger car.

Hence, intentionally choosing roads with inclines, considering the absence of speed humps and the presence of heavy vehicles, enables a more accurate calculation of the minimum operating speed of vehicles. This enhances the precise assessment of the equivalent passenger car in the study.

3.5 Sample size

It refers to the number of individual samples included in a survey or study. It plays a crucial role in research design as it directly influences the reliability and generalizability of the findings. To determine the sample size for estimating vehicle speeds, this study followed the procedure outlined in the Highway Capacity Manual (HCM). The HCM provides a formula for calculating the required sample size, taking into consideration statistical considerations and utilizing Cochran's formula, which is commonly used when the population size is unknown."

$$n = \left(\frac{z\sigma}{E}\right)^2 \dots\dots\dots \text{Equation 3.1}$$

n= sample size

E= is the desired margin of error (expressed as a fraction)

Z= the value given for the given confidence interval

σ= is the standard deviation of the vehicle speeds in the study area

In this research, the assumed standard deviation is σ=0.5. The confidence interval, also known as the margin of error, represents the level of random sampling error in survey results, and in this case, it is set to 0.05. This implies that there is a 95% probability that the survey result has no error. By referring to the standard normal distribution table, the corresponding value of z is determined to be 1.96.(Singh and Masuku n.d.)

Using the above equation: $n = \left(\frac{zpq}{E}\right)^2$, pq= σ

$$n = \frac{(1.96)^2(0.5)}{(0.05)^2} \quad \underline{\underline{n \sim 384}}$$

3.6 Data Collection Method

3.6.1 Data Source

This research uses the primary and secondary source of data for all variables.

Primary data: data which is gathered by the researcher for the first time. These data are:

- Obtained from field in the form of linear measurement (Tarry n.d.).
 - A trap length of 100m used in this research due to the following reasons:

- ✓ A 100m distance provides an adequate length for capturing the speed of vehicles accurately. It allows enough time for vehicles to accelerate or decelerate, providing a reliable measure of their speed.
- ✓ The 100m distance allows for a smooth transition for vehicles traveling along the upgrade section. It ensures that vehicles have enough distance to adjust their speed according to the road conditions, minimizing abrupt speed changes and ensuring a more representative speed measurement.
- ✓ A longer distance, such as 100m, increases the sample size of vehicles observed for speed calculation. This larger sample size improves the statistical validity of the speed measurements and reduces the potential influence of outliers or individual vehicle behavior.
- ✓ In some transportation guidelines and practices, a 100m distance is commonly used for speed calculations. Adopting this standard distance ensures consistency with established methodologies and facilitates comparisons with other studies or historical data.
- ✓ A 100m distance allows adequate observation of vehicle speed without compromising the safety of the data collectors or other road users. It strikes a balance between obtaining accurate speed measurements and maintaining a safe working environment during data collection.
- The road grade will be determined by collecting survey data and creating a plan profile, which involves measuring the elevation changes along the road.
- Video graph survey: Recording the movement of vehicle traffic in one direction on selected road sections and record the entry and exit time of the vehicle. In relation to this, the following listed steps are used:
 - Preparing the appropriate site among the selected study area for video recordings
 - Preparing traffic data collection formats, which is attached as Annex A of this paper.
 - Undertaking proper video recording and carrying out proper data collection according to the data recording schedule.

Secondary data: information collected or adopted from an alternative source. For this research,

- The average area of vehicles is sourced from the literature (Tadiyos Marie and Addis Ababa 2021).

3.6.2 Data Collection Schedule

- Traffic data will be collected at peak traffic conditions observed in the specified up-grade Sections of Addis Ababa. The traffic data will be collected for 4-hour at peak hour between 4:00am – 10:00pm local time on week time of Tuesday, Wednesday, and Thursday. Because:
 - From site observation, in Addis Ababa high traffic flow observed on weekday morning & evening time, the medium traffic flow observed on afternoon and free traffic flow on Sunday. So, Monday & Friday will be excluding from data collection dates as high & low traffic observed in these days respectively on the road of Addis Ababa. As a result, Tuesday, Wednesday, and Thursday were selected for this research considering that these days can represent the correct traffic condition of the city. (Firehun., March, 2019)
 - The local time between 4am to 10 pm selected, to get good vehicle combination since large vehicles are allowed in the city of Addis Ababa during said time as shown in figure 3.10 and this research includes large vehicles as one vehicle classification type.

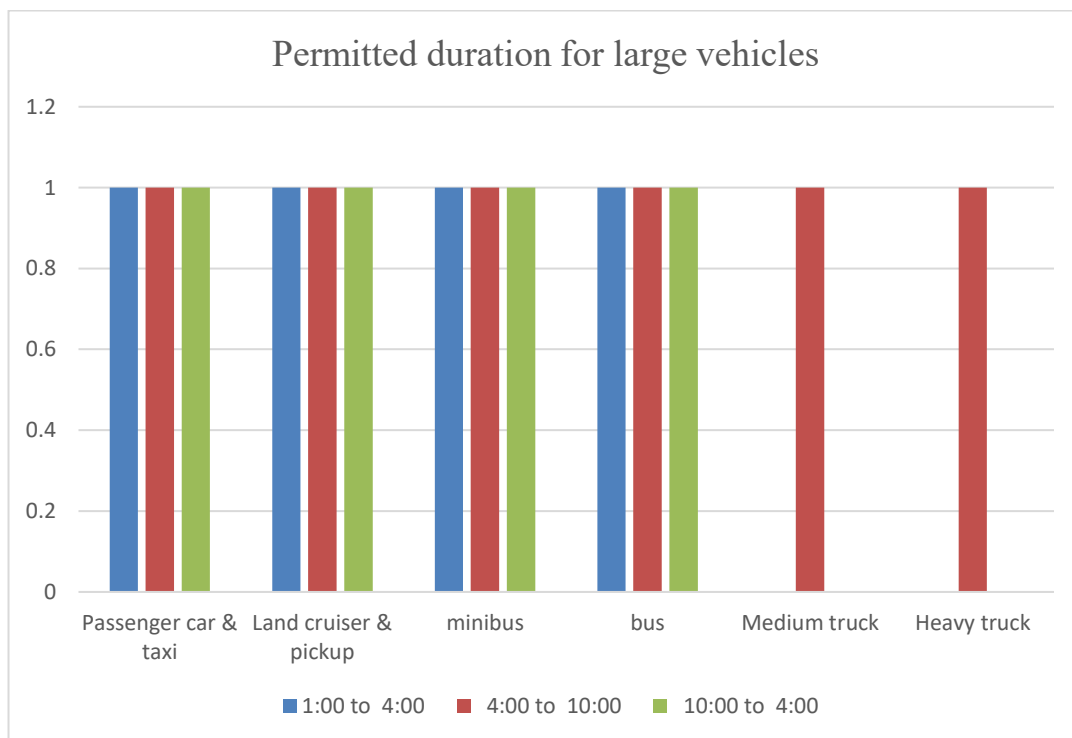


Fig 3.10 Permitted duration for large vehicles.

- Speed data for vehicles was collected for 15-minute within a 1-hour timeframe, capturing a substantial volume of vehicles compared to the data gathered over the entire 4-hour period.

Table 3.2 Summary of road segments traffic volume data collection schedule

Road segment	Trap length of study	Video Recording station	Recording date
Gojam ber – Entoto	1.2km	Around park of entoto	Thursday
Abem – kotebe kara	0.8km	Near to kotebe kara	Wednesday
18 mazoriya – new ambo road	1.0km	Near to 18 mazoriya	Thursday
Goro – Jacros	0.51km	Near to jacros	Tuesday

Table 3.3 Summary of road segments vehicle speed data collection schedule

Road segment	percent of upgrade	Video Recording station	Recording time	Recording date
Gojam ber – Entoto	4.04%	100m from OilLibya	15 minutes (8:pm -9:pm)	Thursday
	7.45%	Around Sheger FM 102.1		
	2.92%	400m from Sheger FM 102.1		
Abem – kotebe kara	10.28%	450m form Abem Hotel	15 minutes (7:pm -8:pm)	Wednesday
	7.68%	600m from Abem Hotel		
18 mazoriya – new ambo road	5.95%	150m from beginning of the segment	15 minutes (5:am -6:pm)	Thursday
	7.34%	600m from kolfe Noc		
	5.88%	350m from kolfe Noc,18 mazoriya		
Goro – Jacros	8.69%	Station 1- around Goro bridge	15 minutes (8:pm -9:pm)	Tuesday
	8.18%	Station 2- 100m from Goro bridge		
	6.36%	Station 3- 200m From Goro Bridge		
	5.45%	Station 4 – 200m from Jacros intersection		
	3.64%	Station 5- 100m from Jacros intersection		

3.6.3 Vehicle Classification

To provide flexibility in subsequent traffic analysis and assessment scenarios, a wide range of vehicle categories were considered in the traffic survey. The vehicle classifications used in this research are based on ERA (Ethiopian Roads Authority) 2013 vehicle classifications and are as follows:

Table 3.4 Vehicle Classification (Ethiopian roads authority 2013)

Class	Type	Axles	Description
1	Car	2	Passenger cars and taxies
2	Pick-up/Wheel drive	2	Pick-up, minibus, land rover, land cruiser
3	Small bus	2	≤27 seats
4	Bus/coach	2	> 27
5	Small truck	2	≤3.5 tones
6	Medium truck	2 or 3	3.5 – 7.5 tonnes
7	Large 2- axled truck	2	>7.5 tonnes
8	3-axled truck	3	>7.5 tonnes
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	*

In this research, the vehicles have been categorized into six types, considering various factors:

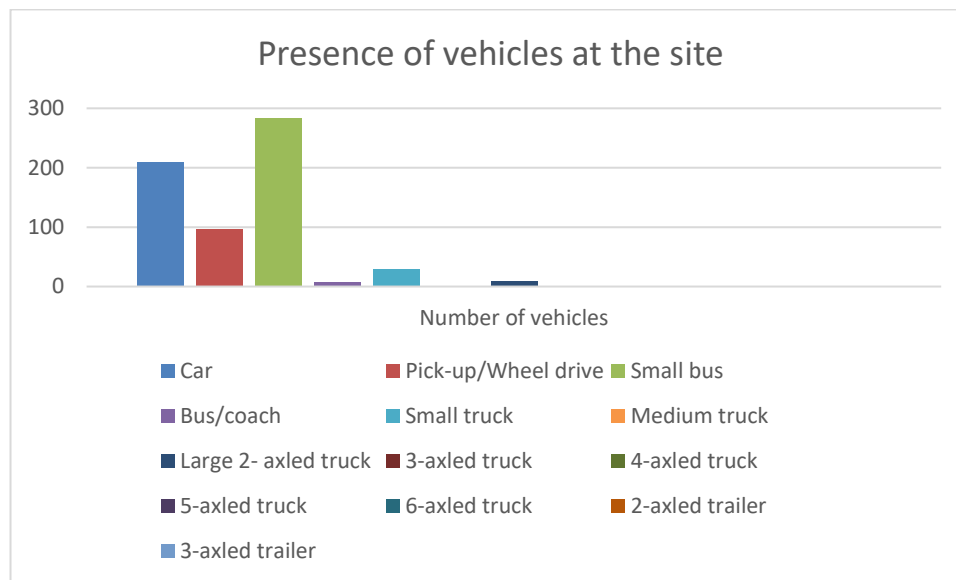


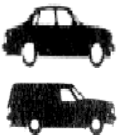





Fig 3.11 Presence of vehicles at the site.

- During site observation vehicles above 7.5 tones or 3-axled trucks are exceptionally rare occurrences on the selected road segments as shown on figure 3.11 so the research isolates these vehicle categories.
- Vehicles with similar lengths, such as pickup trucks and minibuses, were categorized individually based on their differing widths.

- Vehicles with both similar length and width characteristics, such as small trucks and medium trucks (having 2 axles), were merged and treated as a single category.

3.6.3.1 Projected area of vehicles

Table 3.5 Projected area of a vehicle

Vehicle type	PC	Pickup & LC	Minibus/ small bus	Standard Bus/coach	Small truck/ Medium truck (2 axles)	Medium truck (3 axles)/Heavy Good vehicles
						
Length(m)	3.2	4.6	4.6	7.7	6.6	11.5
Width(m)	1.7	1.8	1.9	2.2	2.2	2.7
Projected Area (m ²)	5.44	8.28	8.74	16.94	14.52	31.05

Source:(Tadiyos Marie 2021)

Accordingly, for this research, small cars will be considered as the reference vehicle for passenger cars. By using small cars as the reference vehicle, the PCE (Passenger Car Equivalence) of other vehicle types will be estimated.

3.7 Data Extraction

The collected raw data translated to a set of valuable, usable information and more readable format such as a graph, report, or chart. Also, extracting traffic data from the video recording file, review and organize the collected traffic data, Prepare the paper row data with organize way and record to excel for further analysis will be done here.

3.8 Data Processing

The researcher collected relevant information regarding the study characteristics and findings from the included studies and organized them into an unstructured data format to gain meaningful insights. This data is then made available for reporting, analytics, or further processing into a structured data format.

3.8.1 Determination of flow rate

The traffic volume will be measured by counting the number of vehicles that pass a fixed line from the recorded video.

$$\text{Flow rate } (q) \left(\frac{\text{veh}}{\text{hr}} \right) = \frac{\sum \text{number of vehicle}}{\text{time interval}(\text{min})} * 60$$

3.8.2 Determination of Travel time

The travel time of vehicles is determined by comparing the lengths of designated traps at their entry and exit points using license plate matching from extracted video data. This involves monitoring and recording the movement of vehicles within specific sections of the road, and the calculated difference in trap lengths provides a quantitative measure of the time taken for vehicles to travel through the monitored zone.

$$\text{Time}(\text{sec}) = \text{time2}(t2) - \text{time 1}(t1)$$

3.8.3 Determination of number of Lane

The number of lanes will be determined on the field by visualization.

3.8.4 Determination of vehicle Length and width

As this research focuses on mixed traffic, measuring the length and width of different vehicles in the field may be difficult. Therefore, the width and length of each vehicle will be obtained from literature (Tadiyos Marie and Addis Ababa 2021). Refer Table 3.5, which provides the projected area of a vehicle.

3.8.5 Determination of Composition of vehicle

Traffic composition will be calculated by dividing each vehicle flow by the total flow of vehicles within the given stretch.

$$\text{Vehicle composition } (\%) = \frac{\text{flow of Each vehicle type}}{\text{Total flow of vehicle (in 1hr)}} * 100$$

3.8.6 Determination of travel speed

The travel speed is calculated by dividing distance by time, utilizing the video data obtained through the formula below.

$$\text{Travel speed} \left(\frac{\text{km}}{\text{hr}} \right) = \frac{\text{Distance}(m)}{\text{Time}(s)} * 3.6$$

3.8.7 Assessing the approaches for Speed Determination

Two methods employed to determine speed. The first method involved calculating the speed using the 85th percentile speed calculation. This method considers the speed at which 85% of the vehicles in the traffic data are traveling at or below, providing a representative measure of the typical speed in the given conditions.

Additionally, an Artificial Neural Network (ANN) model was employed to produce an additional set of speed data. The ANN model considers various input parameters and uses a computational approach to predict the speed based on the trained model. This generated speed data provides an alternative estimation of the 85th percentile speed based on the characteristics and patterns identified by the ANN.

By employing both the 85-percentile speed calculation and the ANN-generated speed data, this research aims to capture a comprehensive understanding of the average travel speed along each grade section, allowing for a more robust analysis of the traffic conditions and their implications for passenger car equivalence.

- To calculate the speed using the 85th percentile speed, the study followed the following steps:
Collect speed data for a specific period or location and organize it in ascending order. To calculate the 85th percentile speed, find the mean and frequency. Then, determine the cumulative frequency, and employ interpolation to identify the 85th percentile interval.
- To calculate the predicted speed using an Artificial Neural Network (ANN) model, the study follows these steps:
Artificial Neural Network (ANN) for prediction involves several key steps. First, the neural network is designed and configured, specifying the number of inputs, hidden layers, and output nodes. The network is then trained using a dataset, adjusting the weights and biases to minimize the difference between predicted and actual outcomes. Once trained, the ANN is validated using a separate dataset to ensure generalization to new data. The choice of training algorithms and transfer functions is critical, with parameters optimized to strike a balance between model complexity and accuracy. Model evaluation involves assessing performance metrics, such as root-mean-square error and mean absolute percentage error. The trained and validated ANN is then ready for predictions, generating reliable forecasts based on the learned patterns in the input data.

Methods for PCE estimation

Considering various methods discussed in the literature review for estimating Passenger Car Equivalence (PCE), the dynamic PCE method was specifically selected for this study. This method considers the interaction between traffic flow, flow characteristics, and the projected area of vehicles. As highlighted by Chandra and Sikdar (2000), it provides a more accurate representation of occupancy in situations where strict lane adherence is not observed. Furthermore, Chandra's research showed that the PCU value of vehicles in mixed traffic conditions is directly proportional to the speed ratio and inversely proportional to the space occupancy ratio compared to a standard design vehicle. Due to unique traffic behavior and heterogeneity observed in selected areas, there is a notable variation in how vehicles navigate space, often deviating from traditional lane-based movement. This non-lane-based traffic behavior implies a more dynamic interaction among vehicles, potentially influenced by factors such as informal road usage, unique road geometries, or specific local traffic norms (Firehun., March, 2019). The term "heterogeneity" underscores the diverse nature of this traffic behavior, suggesting a mix of vehicle types, speeds, and maneuvers that contribute to the complexity of the traffic environment in these chosen locations. Therefore, the dynamic PCE method is well-suited for accurately estimating PCE in this specific local context. Equation 2.1 is utilized in this estimation process.

$$\text{Passenger car equivalence (PCU}_i) = \frac{V_c/V_i}{A_c/A_i}$$

Where, V_c denotes the 85 %ile speed of standard car, V_i 85%ile speed vehicle type i

A_c and A_i denotes their respective projected rectangular area.

4. ANALYSIS, RESULT AND DISCUSSION

The subsequent section will delve into the assessment of Statistical summary for the collected data, an exploration of Traffic Flow and Traffic Composition, an analysis of Average Travel Speed Calculation, training of ANN Model for speed prediction, a comprehensive discussion on the Computation of Passenger Car Equivalents and develop a model for the computed PCE values.

4.1 Statistical Summaries for the collected Data

Table 4.1 Statistical Summaries for collected data

Variable	Observation (No)	Mean (km/hr)	85%ile (km/hr)	SD (km/hr)
Vehicle Speed	1086	26.73	33.90	7.08

The statistical summaries regarding measure of tendency and variability show:

Mean vs. 85th Percentile Speed: The 85th percentile speed (33.90) is slightly higher than the mean speed (26.73) suggests that a substantial portion of the vehicles experience speeds significantly higher than the average. This could indicate the presence of periods of faster traffic or occasional higher-speed conditions.

Standard Deviation: The SD (7.08) indicates moderate variability in the speed data. This suggests that while most vehicles may be clustered around the mean speed, there are still considerable fluctuations in speeds, leading to the observed spread in data points.

Traffic Conditions: The combination of a higher 85th percentile speed and a moderate standard deviation implies a mix of different vehicle behaviors within the traffic environment. Some vehicles are moving at higher speeds, contributing to the higher 85th percentile, while others might be traveling at slower speeds, contributing to the spread represented by the standard deviation.

Therefore, the data indicates a traffic scenario where a significant proportion of vehicles experience speeds higher than the mean, while the variability in speeds contributes to a moderate standard deviation. This suggests a diverse traffic environment with potential implications.

4.2 Traffic flow and Traffic composition

Traffic flow data were gathered over four hours, with hourly manual counts from the recorded videos. Information, such as the composition of traffic and flow rates, was gathered from the direction facing uphill within one direction (refer to Annex B for further information).

4.2.1 Traffic flow of study areas

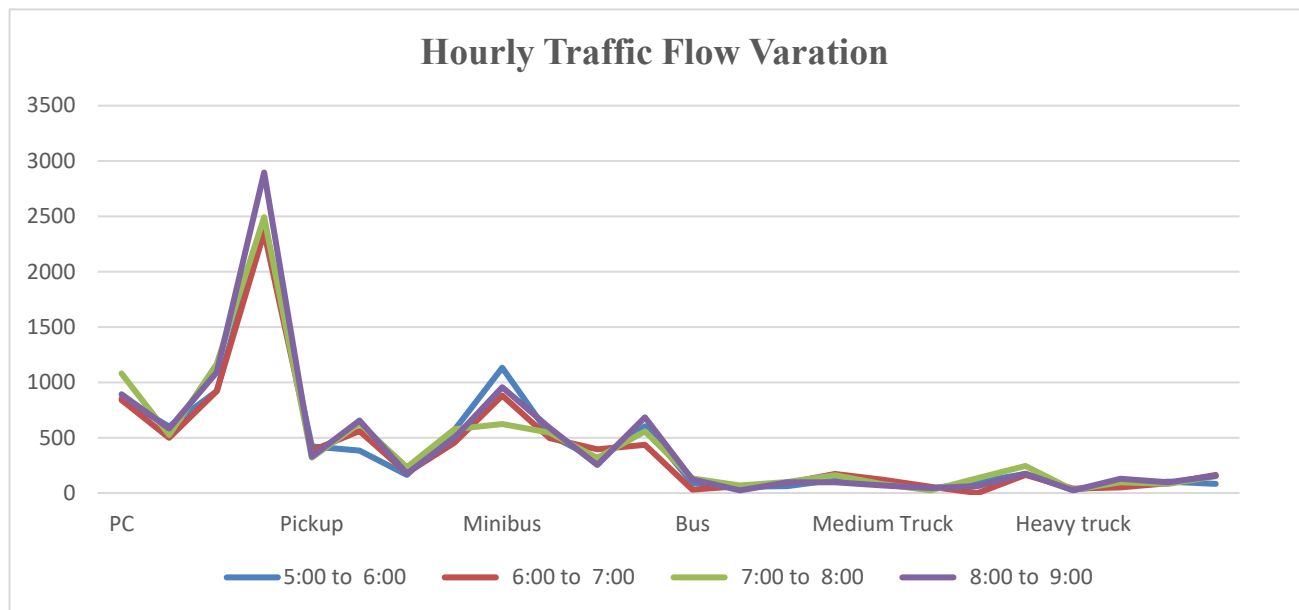


Fig 4.1 Traffic Composition along all Areas.

Figure 4.1 shows fluctuations in traffic flow across different vehicle types. The data indicates that, overall, there is a higher prevalence of passenger cars (PC), pickups, and minibuses in all areas. This observation suggests that these specific vehicle types dominate the traffic landscape in the selected areas.

4.2.2 Traffic composition

4.2.2.1 Traffic Composition of study area one

This study area has a two-way one lane road in each direction with high traffic flow that connects Gojamber Ring Road to Entoto. The composition of vehicles observed is presented below.

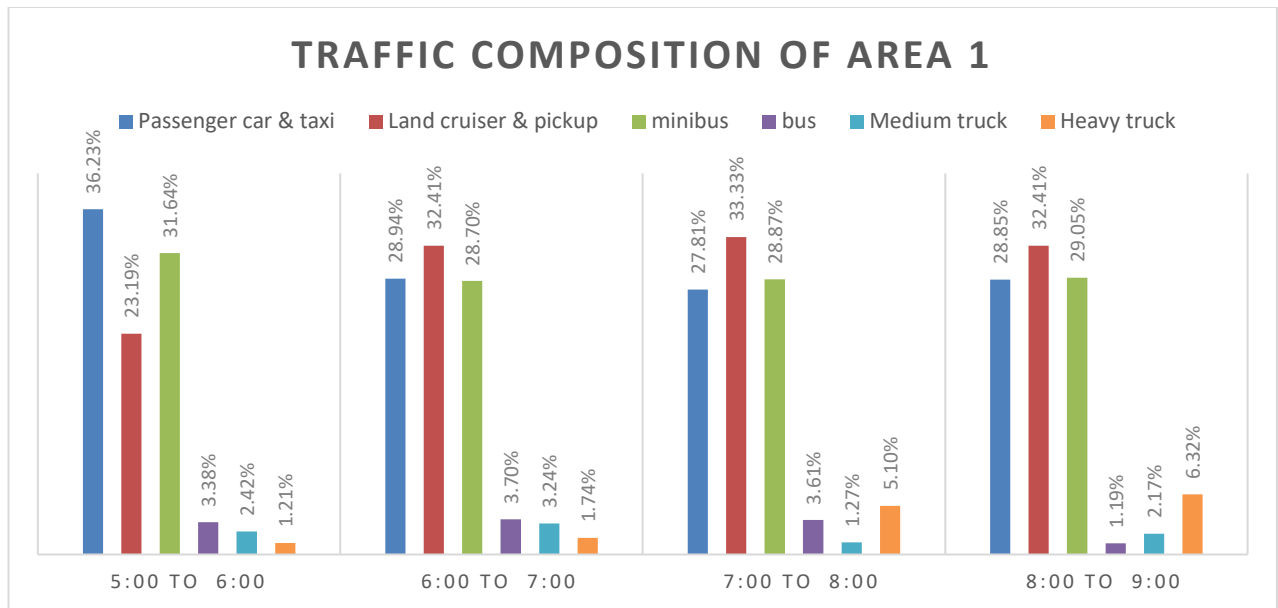


Fig 4.2 Traffic Composition of Area 1.

Based on Figure 4.2 it is evident that in study area one, the composition of pick up, passenger cars and minibuses is significantly higher compared to other vehicle types. On the other hand, buses, heavy trucks, and medium trucks account for varying percentages ranging from 1.2% to 6.3% of the total vehicles observed in each hourly dataset within the 4-hour recording period.

4.2.2.2 Traffic composition of study area Two

This study area has a two-way one lane road in each direction with high traffic flow that connects 18 mazoniya to New Ambo Road. The composition of vehicles observed is presented below.

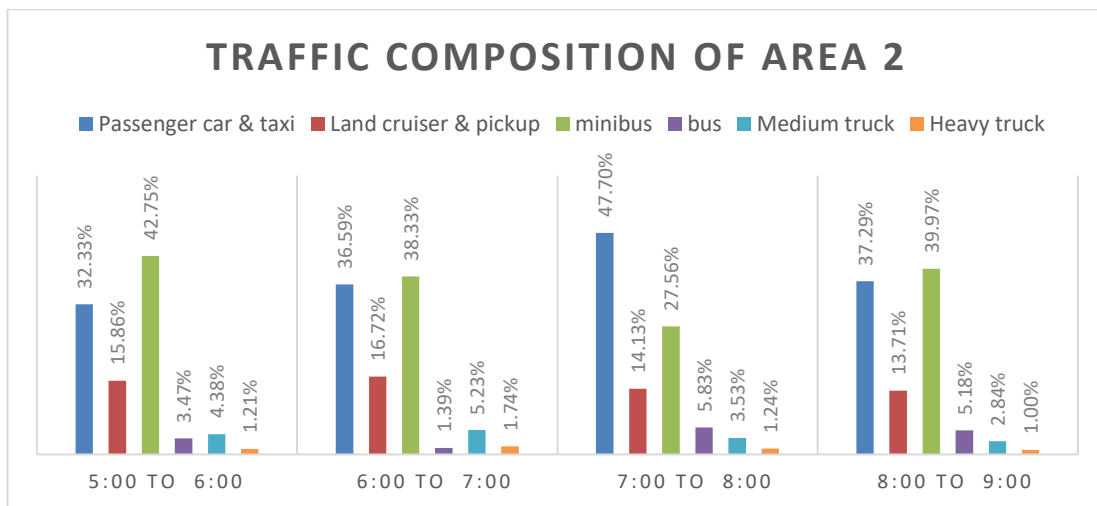


Fig 4.3 Traffic Composition of Area 2.

Based on Figure 4.3, it is noticeable that in study area two, the composition of minibuses and passenger cars is significantly higher compared to other vehicle types. On the other hand, heavy trucks, pickup, buses, and medium trucks account for varying percentages ranging from 1.2% to 16.7% of the total vehicles observed in each hourly dataset within the 4-hour recording period.

4.2.2.3 Traffic composition of study area Three

This study area has a two-way three lane road in each direction with high traffic flow that connects Abem to Kotebe Kara. The composition of vehicles observed is presented below.

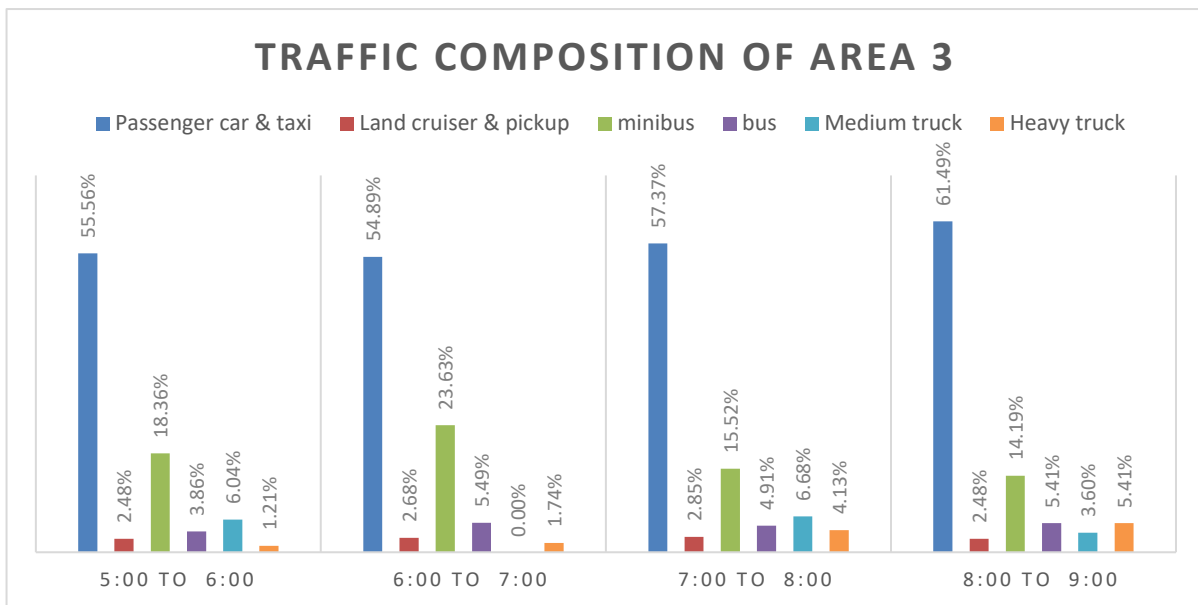


Fig 4.4 Traffic Composition of Area 3.

According to the findings in study area three, the composition of passenger cars is significantly higher compared to other vehicle types. The percentage distribution of different vehicle types in this area indicates that minibus, heavy trucks, buses, and medium trucks range from 1.2% to 23.6% of the total vehicles observed in each hourly dataset within the 4-hour recording period.

4.2.2.4 Traffic composition of study area Four

This study area has a two-way three lane road in each direction with high traffic flow that connects Goro to Jacros. The composition of vehicles observed is presented below.

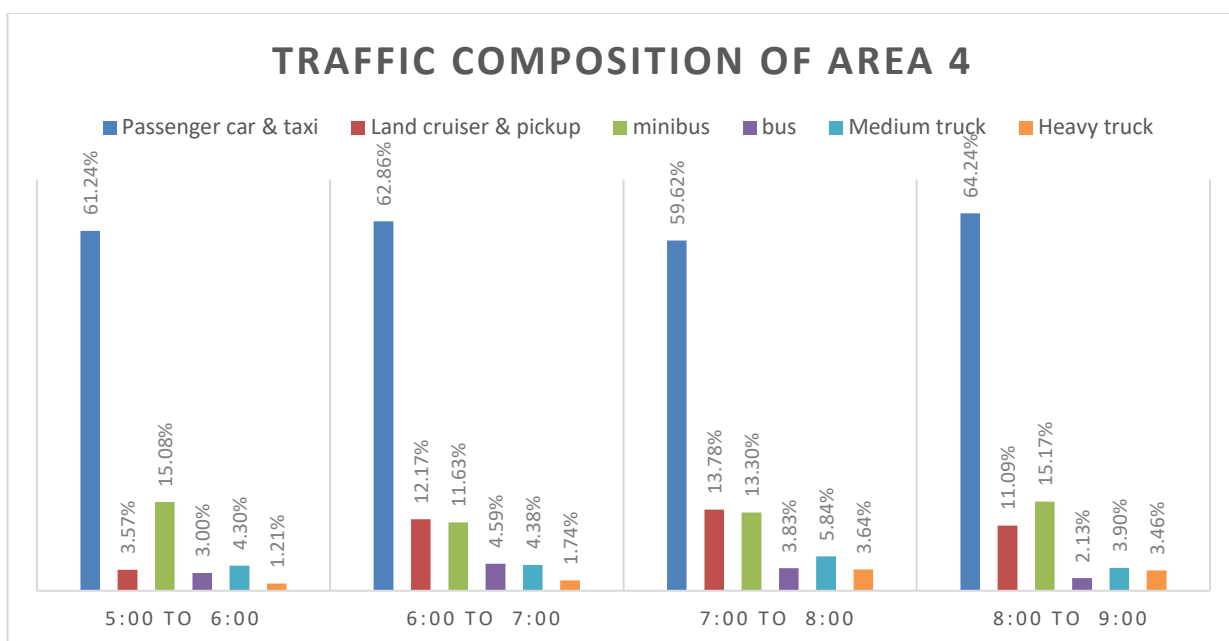


Fig 4.5 Traffic Composition of Area 4.

According to the findings in study area four, the composition of passenger cars is higher compared to other vehicle types during peak hours. The percentage distribution of different vehicle types in this area, as presented in Table 4.5, indicates that minibus, heavy trucks, buses, and medium trucks range from 3.9% to 15.1% of the total vehicles observed in each hourly dataset within the 4-hour recording period.

➤ Result of Traffic composition of all areas:

Table 4.2 Impact of Standard Bus, Medium Trucks (MT) & Heavy Truck (HT)

Study Areas	Area 1	Area 2	Area 3	Area 4
Composition Percentage (MT&HT)	8.50%	5.59%	10.81%	7.36%
Composition Percentage (Bus, MT & HT)	9.68%	9.08%	15.72%	9.49%

Table 4.2 illustrates the impact assessment of buses, medium trucks, and heavy trucks by identifying a time frame characterized by a higher volume of vehicles and isolating the specific composition within that period. Accordingly, the data from the table demonstrates that Area 3 is noticeably affected by these vehicle types in comparison to the other three segments.

The impact analysis specifically focuses on these vehicles due to the classification of buses as heavy vehicles according to the HCM manual, shown in Table 2.1. This categorization is essential for

determining the Passenger Car Equivalent (PCE) value. Hence, the study specifically singles out these vehicle types to align the outcomes with the classification guidelines outlined in the HCM manual.

4.3 Speed calculation

4.3.1 Speed calculation using 85 percentile speed calculation method.

A sample of data was collected for all routes to determine the speed using the 85th percentile speed calculation method. As an example, let's consider the route from 18 mazoriya to Ambo Road at grade 7.34%.

Table 4.3 calculation of recorded speed data

18 mazoriya to Ambo Road at grade 7.34%											
No	vehicle	Entry time (sec)	Exit time (sec)	actual time (sec)	speed (km/hr)	No	vehicle	Entry time (sec)	Exit time (sec)	actual time (sec)	speed (km/hr)
1	H Truck	45	55	10	36.00	23	Minibus	435	447	12	30.00
2	Bus	48	62	14	25.71	24	Pc	458	470	12	30.00
3	Pc	50	65	15	24.00	25	Minibus	462	472	10	36.00
4	Pc	53	67	14	25.71	26	M truck	490	502	12	30.00
5	Minibus	58	68	10	36.00	27	Pc	492	503	11	32.73
6	Minibus	61	73	12	30.00	28	Minibus	494	508	14	25.71
7	MT	63	75	12	30.00	29	Pc	518	530	12	30.00
8	Minibus	67	79	12	30.00	30	Minibus	521	532	11	32.73
9	Minibus	69	82	13	27.69	31	Pc	514	527	13	27.69
10	Pc	77	96	19	21.18	32	Pc	554	565	11	32.73
11	Bus	88	103	15	24.00	33	Minibus	560	569	9	40.00
12	Pc	125	140	15	24.00	34	Pc	575	586	11	32.73
13	Pc	238	250	12	30.00	35	Pc	579	588	9	40.00
14	Minibus	240	252	12	30.00	36	Pc	580	590	10	36.00
15	H Truck	328	341	13	27.69	37	Pick up	599	612	13	27.69
16	Pick up	347	361	14	25.71	38	Pc	601	613	12	30.00
17	Pc	356	370	14	25.71	39	Minibus	602	617	15	24.00
18	Pc	385	396	11	32.73	40	Minibus	605	620	15	24.00
19	Pick up	404	418	14	25.71	41	Pc	614	628	14	25.71
20	Minibus	412	424	12	30.00	42	Minibus	623	635	12	30.00
21	Minibus	422	433	11	32.73	43	Minibus	642	655	13	27.69
22	Pc	431	442	11	32.73	44	Minibus	646	662	16	22.50

Upon calculating the speed for the given grade, ascertain the speed corresponding to the 85th percentile using the calculation procedure defined in Table 4.4. The summary pertaining to a road featuring a 7.34% grade corresponds with the data provided in Table 4.5.

Table 4.4 Sample Calculation of the 85th percentile speed for a road with a 7.34% grade

Vehicle Speed along (15 min)							
Passenger car 7.34% grade road							
speed range (km/hr)		frequency(fi)	mean (Average speed) (ui)	fi*ui	(%) frequency	Cumulative frequency (%)	fi (ui- \bar{u}) ²
15	20	0	17.5	-	0.00	0.00	-
20	25	2	22.5	45.00	11.11	11.11	104.32
25	30	9	27.5	247.50	50.00	61.11	44.44
30	35	5	32.5	162.50	27.78	88.89	38.58
35	40	1	37.5	37.50	5.56	94.44	60.49
40	45	1	42.5	42.50	5.56	100.00	163.27
		18		535.00			411.11

Table 4.5 Summary of 85 percentile speed for all vehicles along grade 7.34%

Vehicle type	85 th ile Vehicle speed (km/hr)
Passenger Car	31.80
Pickup	26.75
Minibus	33.63
Bus	26.00
Medium Truck	26.75
Heavy Truck	36.00

In Table 4.5, for a 7.34% slope road, most vehicles travel at speeds like 31.80 km/hr for cars, 26.75 km/hr for pickups, 33.63 km/hr for minibuses, 26.0 km/hr for buses, 26.75 km/hr for medium trucks, and 36.0 km/hr for heavy trucks. Notably, heavy trucks go a bit faster than the rest. This happens because, as observed in the videos, when heavy trucks approach the area, they come in faster than other vehicles. Their high entry speed means other vehicles don't overtake them, so heavy trucks keep their speed until they finish going uphill. This shows that how fast vehicles come in at the start (entry speed) really affects how they move on uphill roads.

4.3.2 85th percentile speed variation among all roads

Table 4.6 Summary of 85 percentile speed for all vehicles along all grades

Vehicle type	Three - lane		One - lane		One - way		Three - lane	
	10.28%	7.68%	7.34%	5.95%	2.95%	7.45%	6.36%	8.69%
Passenger car	33.88	31.60	31.8	37.41	41.38	36.14	21.86	29.81
Pickup	34.88	27.45	26.75	40.25	41.00	38.75	21.84	31.25
minibus	37.00	35.10	33.63	38.38	40.10	40.25	21.00	34.82
bus	27.46	27.45	26.00	35.25	35.25	35.25	21.38	25.63
medium truck	23.00	23.00	31.75	35.75	40.50	35.00	21.25	30.75
heavy truck	33.75	33.75	36.00	41.00	35.00	27.25	19.50	23.37

Table 4.6 shows that, in a three-way segment, when the road grade initiates with a high grade, it exhibits a pattern of starting with higher speeds and concluding with lower speeds. Conversely, if the road grade commences with a low hill grade, the pattern is reversed, beginning with lower speeds, and ending with higher speeds.

On a one-way segment, if the road begins with a high uphill grade, the speed is initially low and gradually increases, concluding with higher speeds. Conversely, when the road starts with a low grade, it begins with higher speeds and concludes with lower speeds.

4.3.3 Speed calculation using artificial neural network model.

Training of Artificial neural network model

The ANN will subsequently learn the correlation between road grade, road lane, and their respective vehicle types. This entails converting and representing the input data into a suitable format for the software's training process as shown in a sample in Table 4.7 below.

Table 4.7 Conversion and representation of input data for software (MATLAB)

Conversion of Road grade					
Road grade (%)	Input decimal ($\frac{\%}{100}$)	Road grade (%)	Input decimal ($\frac{\%}{100}$)	Road grade (%)	Input decimal ($\frac{\%}{100}$)
10.28%	0.1028	2.92%	0.0292	3.64%	0.0364
7.68%	0.0768	4.04%	0.0404	8.69%	0.0869
7.34%	0.0734	7.45%	0.0745	8.18%	0.0818
5.88%	0.0588	6.36%	0.0636		
5.95%	0.0595	5.45%	0.0545		

Representation of Road Lane	
Road Lane	Input numeric data
Lane 1	1
Lane 2	2
Representation of Vehicle Type	
Vehicle type	Input numeric data
Passenger Car (PC)	0
Pickup/LC	1
Minibus	2
Standard Bus	3
Medium truck	4
Heavy Truck	5

Steps to Train ANN

Create an Excel spreadsheet containing input and output data following the format presented as an illustrative example in Table 4.8. Import this excel dataset into MATLAB software and open the Neural Network Toolbox app, which allows training and designing neural networks interactively. Then Perform data partitioning to allocate subsets for training (70%), validation (15%), and testing (15%), ensuring appropriate sample representation in each category. Configure the ANN with 25 neurons in the hidden layer and use Levenberg-Marquardt training algorithm, aligning input data and targets for optimal fitting. Initiate the training process by clicking the "train" button in the Neural Network Toolbox app, allowing the network to iteratively adjust its weights and biases to minimize prediction errors as shown in figure 4.6 and figure 4.8 below.

Table 4.8 sample data on excel.

Input data			Output data	Input data			Output data
Vehicle type	Road grade	Road Lane	Vehicle speed	Vehicle type	Road grade	Road Lane	Vehicle speed
5	0.0734	3	36.00	2	0.0734	3	30.00
3	0.0734	3	25.71	4	0.0734	3	30.00
0	0.0734	3	24.00	2	0.0734	3	27.69
0	0.0734	3	25.71	2	0.0734	3	21.18
2	0.0734	3	36.00	0	0.0734	3	24.00



Fig 4.6 Neural network training algorithm.

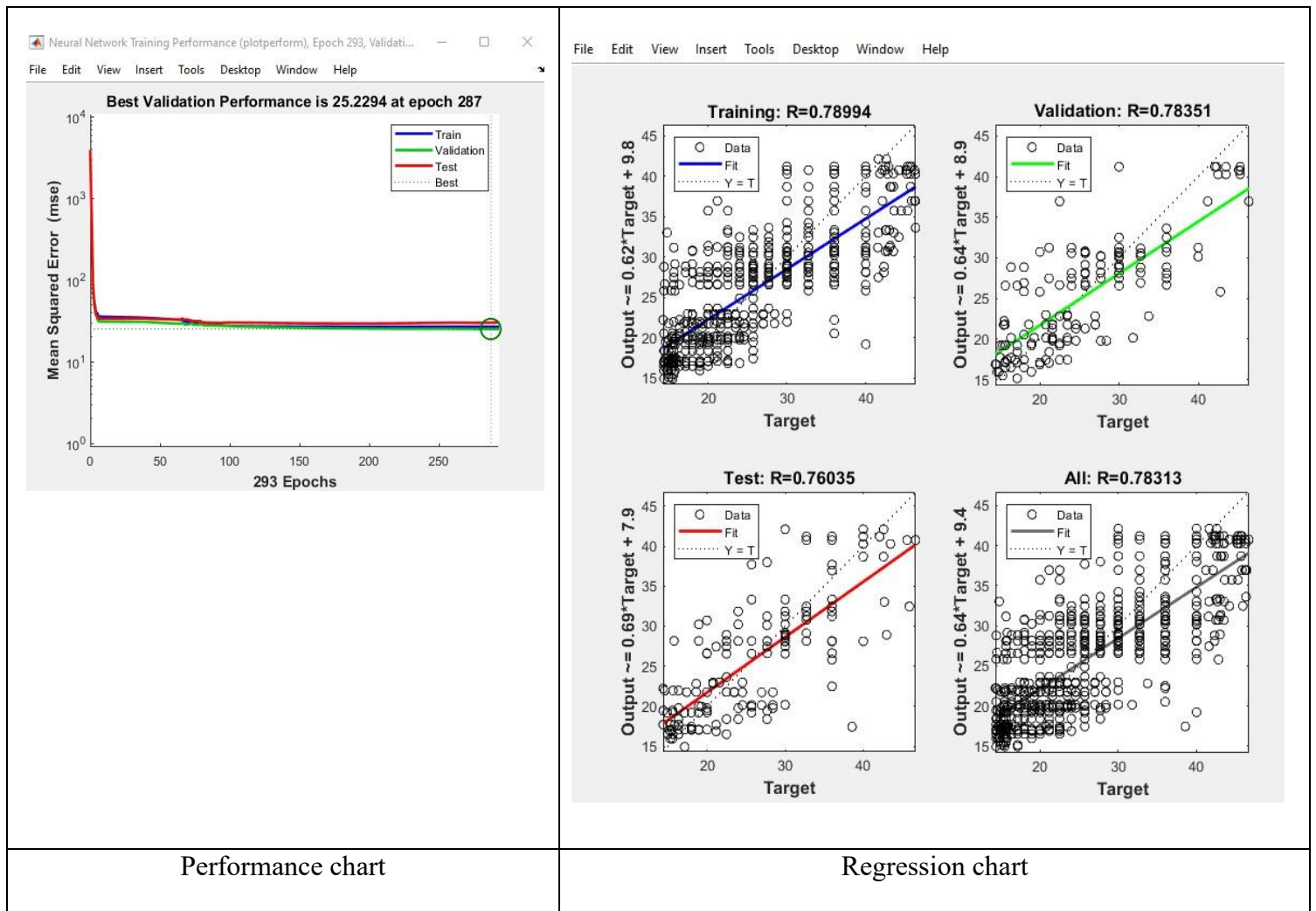


Fig 4.7 Neural network training performance and regression chart.

After the above steps, for speed prediction based on the training result, use the specification stated below and the new input data as shown in Table 4.8 and proceed to MATLAB, utilize Matrix- only function to generate a code and select the “simple script” to load the trial data. Then obtain the output result as shown in Figure 4.7 and Table 4.9.

Sample trial

➤ Specification

For this research the model will be working for the following input specification

A. Road grade

- 2.9% up to 10.8 %

B. Road Lane

- Roads which have only 1 and 2 Lane type

C. Vehicle type

- Passenger car, Pickup, Minibus, Bus, Medium truck, and Heavy truck only

Trial input data and Output data

Enter the trial sample data from excel data into MATLAB.

Input

Table 4.9 sample trial input data on excel

No	Vehicle type	Road Grade	Number of lanes	No	Vehicle type	Road Grade	Number of lanes	No	Vehicle type	Road Grade	Number of lanes
1	5	0.0734	1	16	1	0.0734	1	31	0	0.0734	1
2	3	0.0734	1	17	0	0.0734	1	32	0	0.0734	1
3	0	0.0734	1	18	0	0.0734	1	33	2	0.0734	1
4	0	0.0734	1	19	1	0.0734	1	34	0	0.0734	1
5	2	0.0734	1	20	2	0.0734	1	35	0	0.0734	1
6	2	0.0734	1	21	2	0.0734	1	36	0	0.0734	1
7	4	0.0734	1	22	0	0.0734	1	37	1	0.0734	1
8	2	0.0734	1	23	2	0.0734	1	38	0	0.0734	1
9	2	0.0734	1	24	0	0.0734	1	39	2	0.0734	1
10	0	0.0734	1	25	2	0.0734	1	40	2	0.0734	1
11	3	0.0734	1	26	4	0.0734	1	41	0	0.0734	1
12	0	0.0734	1	27	0	0.0734	1	42	2	0.0734	1
13	0	0.0734	1	28	2	0.0734	1	43	2	0.0734	1
14	2	0.0734	1	29	0	0.0734	1	44	2	0.0734	1
15	5	0.0734	1	30	2	0.0734	1				

Output (Result from MATLAB)

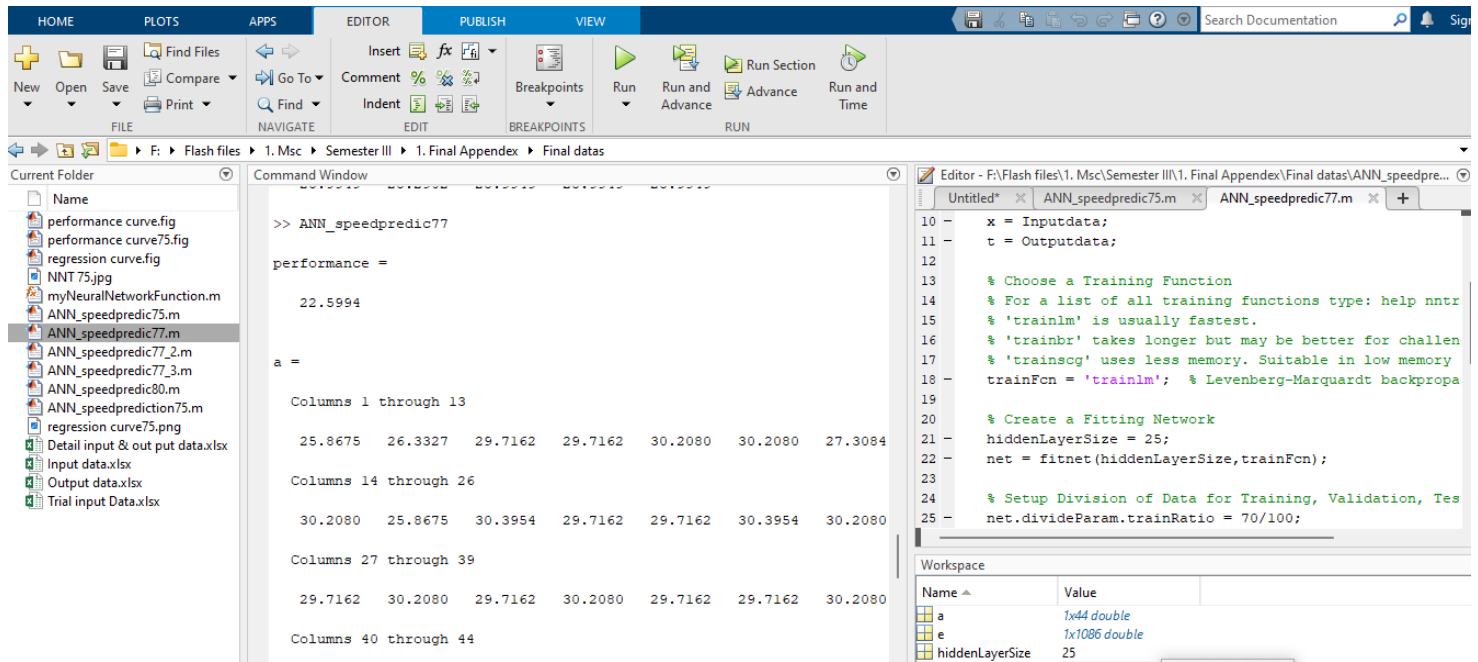


Fig 4.8 predicted Speed output from MAT LAB

The complete outcome derived from Figure 4.8 is presented in Table 4.10 below:

Table 4.10 Output result from ANN

No	Vehicle Speed	No	Vehicle Speed	No	Vehicle Speed	No	Vehicle Speed
1	25.69	12	29.75	23	30.56	34	29.75
2	27.10	13	27.10	24	29.75	35	30.56
3	29.75	14	29.75	25	30.56	36	29.75
4	29.75	15	29.75	26	29.75	37	29.75
5	30.56	16	30.56	27	30.56	38	29.75
6	30.56	17	25.69	28	25.12	39	30.63
7	25.12	18	30.63	29	29.75	40	29.75
8	30.56	19	29.75	30	30.56	41	30.56
9	30.56	20	29.75	31	29.75	42	30.56
10	25.69	21	30.63	32	30.56	43	29.75
11	27.10	22	30.56	33	29.75	44	30.56

4.4 Checking the accuracy of the model

The accuracy of the model was assessed using statistical metrics designed to evaluate predictive model performance, as specified in Equation 2.8, which is presented in Table 4.11. A comprehensive and detailed assessment of the model's accuracy and performance available in Appendix D.

Table 4.11 Results from standard measures of error

Standard measures of error	Results
MAPE	15.74%
RRMSE	16.87%

Mean Absolute Percentage Error (MAPE): The MAPE value is approximately 15.74%. This means that, on average, the predictions have a percentage error of about 15.74% relative to the actual values. A lower MAPE indicates more precision & better predictive accuracy, so a MAPE of 15.74% suggests that the model's predictions are medium precision & relatively accurate and is making predictions that are within a reasonable range of the observed data.

Relative Root Mean Squared Error (RRMSE): The RRMSE value is approximately 16.87%. This indicates that the RMSE, when normalized by the mean of the actual values, accounts for about 16.87% of the average observed value. RRMSE values indicate better predictive precision, so a value of 16.87% suggests that the model's predictions are relatively precise compared to the average observed value.

4.5 Computation of 85 percentile speed for the trial input data

Determine the speed associated with the 85th percentile using the calculation method outlined in Table 4.4. The outcome for a trial data with a 7.34% grade is presented below:

Table 4.12 Sample of 85 %ile speed for Trial data along 7.34% grade

Vehicle type		85%ile Vehicle speed
Passenger Car	0	26.75
Pickup	1	31.75
Minibus	2	31.75
Bus	3	26.75
Medium Truck	4	26.75
Heavy Truck	5	26.75

4.6 Computation of the respective vehicle speed & Projected Area

4.6.1 Calculation of vehicle speed & Projected Area for the recorded data

Compute PCE using the computed 85%ile Vehicle speed for 7.34% grade road in Table 4.5:

Table 4.13 calculation of V_c/V_i and A_c/A_i for recorded data

Vehicle type	85%ile Vehicle speed	V_c/V_i	Projected Area(m ²)	A_c/A_i
Passenger Car	31.80	1.000	5.44	1.000
Pickup	26.75	1.189	8.28	0.657
Minibus	33.63	0.946	8.74	0.622
Bus	26.00	1.223	16.94	0.321
Medium Truck	31.75	1.002	14.52	0.375
Heavy Truck	36.00	0.883	31.05	0.175

4.6.2 Calculation of vehicle speed & Projected Area for the Trial output

Compute PCE using the computed 85%ile Vehicle speed for trial 7.34% grade on one lane road data in Table 4.14:

 Table 4.14 calculation of V_c/V_i and A_c/A_i for trial data

Vehicle type	85%ile Vehicle speed	V_c/V_i	Projected Area(m ²)	A_c/A_i
Passenger Car	26.75	1.00	5.44	1.000
Pickup	31.75	0.823	8.28	0.657
Minibus	31.75	0.823	8.74	0.622
Bus	26.75	0.973	16.94	0.321
Medium Truck	26.75	0.973	14.52	0.375
Heavy Truck	26.75	0.973	31.05	0.175

Table 4.15 PCE Results on Trial Data Vs Recorded data under road grade 7.34 %

Trial data PCE along 7.34%		Recorded data PCE (along 7.34%)	
Vehicle type	$\frac{V_c/V_i}{A_c/A_i}$	Vehicle type	$\frac{V_c/V_i}{A_c/A_i}$
Passenger Car	1	Passenger Car	1.00
Pickup/4WD	1.25	Pickup/4WD	1.81
Minibus	1.32	Minibus	1.52
Standard Bus	3.03	Standard Bus	3.81
Medium Truck	2.60	Medium Truck	2.67
Heavy Truck	5.55	Heavy Truck	5.04

Table 4.15 highlights notable variations in the PCE values of Pickup/4WD, Standard Bus, and Heavy Truck in the trial data when compared to the recorded PCE value results. The research attributes these differences primarily to the predictive capability of Artificial Neural Network (ANN) and the variations in speed exhibited by these vehicles in comparison to the standardized passenger car. As

observed from Table 4.13 & 4.14 the 85th percentile speed of the standard vehicle for recorded and trial data have variation. This variation occurs due to:

- Pickup/4WD: Pickups, especially 4WDs, may have different acceleration and deceleration patterns compared to other vehicles. This can impact how they interact with the road on an uphill slope.
- Bus: they often carry more passengers, and the load they carry can vary. The increased weight or passenger capacity can affect their performance on uphill grades.
- Heavy Truck: they typically have powerful engines, but variations in engine performance or load conditions can influence their ability to navigate uphill slopes. Load conditions, such as carrying a full load, can impact their efficiency.

4.7 Computation of passenger car equivalent

Utilize equation 2 to calculate the equivalence for passenger cars.

Table 4.16 Computation of passenger car equivalence for all Road grades

	Three Lane		One Lane			One Lane			Three Lane				
	Abem -Kara		18 mazoriya - Ambo			Gojam ber entoto			Goro -Jacros				
	10.28%	7.68%	7.34%	5.88%	5.95%	2.95%	4.04%	7.45%	6.36%	5.45%	3.64%	8.18%	8.69%
	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$	$\frac{V_c/V_i}{A_c/A_i}$
Passenger car	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Pickup	1.48	1.75	1.81	1.53	1.41	1.54	1.50	1.42	1.52	1.42	1.50	1.46	1.45
Minibus	1.47	1.45	1.52	1.60	1.57	1.66	1.59	1.44	1.67	1.63	1.61	1.31	1.38
Bus	3.84	3.58	3.81	3.33	3.30	3.66	3.49	3.19	3.18	3.47	3.94	3.87	3.62
Medium truck	3.93	3.67	2.67	2.66	2.79	2.73	2.81	2.76	2.75	2.74	2.72	2.35	2.59
Heavy truck	5.73	5.34	5.04	5.69	5.21	6.75	6.51	7.57	6.40	5.76	6.19	6.60	7.28

4.7.1 Variation of PCE based on their Road Lane

In this study, two types of road lanes were examined: a two-way single-lane road and a two-way six-lane road. The single-lane road has one lane on each side, while the six-lane road has three lanes on each side. Data collection for the study was specifically carried out in one direction, on the uphill side. The PCE values compared for buses, MT, and HT at the beginning and end of the uphill section across two lane groups as shown in Table 4.17 below.

Table 4.17 Variation of PCE based on their Road lanes.

PCE at the start of uphill				
Vehicle type	PCE at the start of Area 1(single lane)	PCE at the start of Area 2 (single lane)	PCE at the start of Area 3 (three lane)	PCE at the start of Area 4 (three lane)
	2.95%	7.34%	10.28%	6.36%
Bus	3.66	3.81	3.84	3.18
Medium Truck	2.73	2.67	3.93	2.75
Heavy Truck	6.75	5.04	5.73	6.40
PCE at the end of uphill				
	PCE at the end of Area 1(single lane)	PCE at the end of Area 2 (single lane)	PCE at the end of Area 3 (three lane)	PCE at the end of Area 4 (three lane)
	7.45%	5.95%	7.68%	8.69%
Bus	3.19	3.30	3.58	3.62
Medium Truck	2.76	2.79	3.67	2.59
Heavy Truck	7.57	5.21	5.34	7.28

Table 4.17 indicates that, during the uphill portion, one-lane roads generally result in higher Passenger Car Equivalence (PCE) values for heavy vehicles at both the beginning and end, in contrast to three-lane roads. Conversely, for buses and medium trucks, three-lane roads show higher PCE values compared to one-lane roads at both the start and end of the uphill stretch.

4.8 Model development for Passenger Car equivalences

In this research, multiple regression model is employed to formulate estimations for passenger car units using SPSS software. The input variables considered were vehicle type (as a dummy variable), vehicle speed and road grade, with the output variable being passenger car equivalence. This choice was made based on the interdependence between vehicle type, vehicle speed and road grade, as the speed of a vehicle is influenced by the road grade and vehicle type. Notably, all vehicle type, vehicle speed and road grade impact passenger car units, and these effects vary for each road lane. Acknowledging the unique influence of vehicle type, vehicle speed and road grade on different Road Lane, individual relationships were established for each road lanes.

In the statistical analysis, a variable with a P-value less than 0.05 is considered statistically significant, indicating its role in explaining the variation in the dependent variable, which, in this study, is passenger car equivalence. The variables considered here are vehicle type (as a dummy variable), vehicle speed and road grade, and their statistical significance was verified. As mentioned earlier, separate relationships were established for the road lanes because lane difference responds differently to changes in vehicle speed and road grade. Consequently, the results of the regression analysis and the correlation between bus, medium truck, heavy truck & PCE for each road lane are outlined in the Tables below.

Table 4.18 Correlation between Bus, MT, HT and PCE on one-lane road

	PCE	Bus	Medium Truck	Heavy Truck
PCE	1			
Bus	-0.206	1		
Medium Truck	-0.583	-0.492	1	
Heavy Truck	0.810	-0.333	-0.656	1

Table 4.19 Regression output on one-lane roads

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	8.141	.812		10.023	.000
Road grade (G)	-20.151	7.970	-.152	-2.528	.014
Vehicle Speed (Vs)	-.118	.018	-.389	-6.482	.000
Bus	.244	.358	.042	.681	.498
Heavy Truck (HT)	3.948	.312	.779	12.644	.000

a. Dependent Variable: PCE

Table 4.20 Excluded Variable on one-lane road.

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
Medium Truck	. ^b	.	.	.	.000

a. Dependent Variable: PCE

b. Predictors in the Model: (Constant), Heavy Truck, Road grade, Vehicle Speed, Bus

Table 4.21 Correlation between Bus, MT, HT and PCE on three-lane road

	PCE	Bus	Medium Truck	Heavy Truck
PCE	1			
Bus	-0.278	1		
Medium Truck	-0.689	-0.330	1	
Heavy Truck	-0.865	-0.432	-0.708	1

Table 4.22 Regression output on three-lane roads

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.729	.341		13.860	.000
Road grade (G)	29.242	2.838	.301	10.303	.000
Vehicle Speed (Vs)	-.155	.013	-.341	-11.651	.000
Bus	.517	.162	.098	3.188	.002
Heavy Truck (HT)	3.461	.121	.880	28.491	.000

a. Dependent Variable: PCE

Table 4.23 Excluded Variable on three-lane road.

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
Medium Truck	. ^b	.	.	.	.000

a. Dependent Variable: PCE

b. Predictors in the Model: (Constant), Heavy Truck, Road grade, Vehicle Speed F, Bus

Table 4.24 Correlation between Bus, MT, HT and PCE on both-lane road

	PCE	Bus	Medium Truck	Heavy Truck
PCE	1			
Bus	-0.248	1		
Medium Truck	-0.645	-0.382	1	
Heavy Truck	-0.833	-0.398	-0.696	1

Table 4.25 Regression output on both-lane roads

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-14.353	3.090		-3.540	.001
Road grade (G)	125.750	19.939	1.273	6.307	.000
Vehicle Speed (Vs)	.0045	.020	.142	2.216	.028
Bus	0.405	.200	-.563	-15.065	.000
Heavy Truck (HT)	3.413	.156	-.815	-21.831	.000
LOG(G2*Vs)	-8.101	1.316	-1.238	-6.158	.000

a. Dependent Variable: PCE

Table 4.26 Excluded Variable on both-lane road.

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
					Tolerance
Medium Truck	. ^b	.	.	.	.000

a. Dependent Variable: PCE

b. Predictors in the Model: (Constant), Heavy Truck, Road grade, Vehicle Speed, Bus

4.8.1 Model interpretations

After completing the regression analysis, a separate equation model was formulated, using vehicle type, vehicle speed and road grade as the independent variables. The specific values for the constants and coefficients refer to each vehicle category are provided in the Table 4.27 below.

Table 4.27 Values of constants and coefficient of determination for the developed mode

Road Lanes	(Constant) (a)	G (B ₀)	V _s (B ₁)	B (B ₂)	HT (B ₃)	LOG (G ² *V _s) (B ₄)	R ²	Adjusted R ²
One - lane	8.141	-20.151	-0.118	0.244	3.948		0.802	0.789
Three - Lanes	4.729	29.242	-0.155	0.517	3.461		0.905	0.902
Both - Lane	-14.353	125.750	0.0045	0.405	3.413	-8.101	0.785	0.779

$$PCE_{1L} = a - (B_0 * G) - (B_1 * V_s) + (B_2 * B) + (B_3 * HT)$$

$$PCE_{1L} = 8.141 - (20.151 * G) - (0.118 * V_s) + (0.244 * B) + (3.948 * HT) \dots\dots\dots \text{Equation 4.1}$$

$$PCE_{3L} = a - (B_0 * G) - (B_1 * V_s) + (B_2 * B) + (B_3 * HT)$$

$$PCE_{3L} = 4.729 + (29.242 * G) - (0.155 * V_s) + (0.517 * B) + (3.461 * HT) \dots\dots\dots \text{Equation 4.2}$$

$$PCE_{BL} = - a + (B_0 * G) + (B_1 * V_s) + (B_2 * B) + (B_3 * HT) - (B_4 * \text{LOG} (G^2 * V_s))$$

$$PCE_{BL} = -14.353 + (125.750 * G) + (0.0045 * V_s) + (0.405 * B) + (3.413 * HT) - (8.101 * \text{LOG} (G^2 * V_s)).. \text{Equation 4.3}$$

Where:

a=constant, B₀, B₁, B₂, B₃, & B₄ = coefficients

V_s= Vehicle speed, G= Road Grade, B=Bus, HT=heavy truck

PCE_{1L} =passenger car equivalence of one-lane,

PCE_{3L} =passenger car equivalence of three-lane,

PCE_{BL} =passenger car equivalence of both-lane,

4.8.2 Model validation

It is essential to validate the developed model to assess its predictive performance for future values, whether applied within the same city or in other locations facing similar challenges. In this research, external validation was carried out for each model to confirm its predictive accuracy. The R^2 value, exceeding 0.8, signifies a reliable prediction, as detailed below. As previously noted, considering the varied impact of traffic speed, vehicle type and road grade relationships were established for each road lane. Therefore, validation procedures were also conducted separately for each road lane.

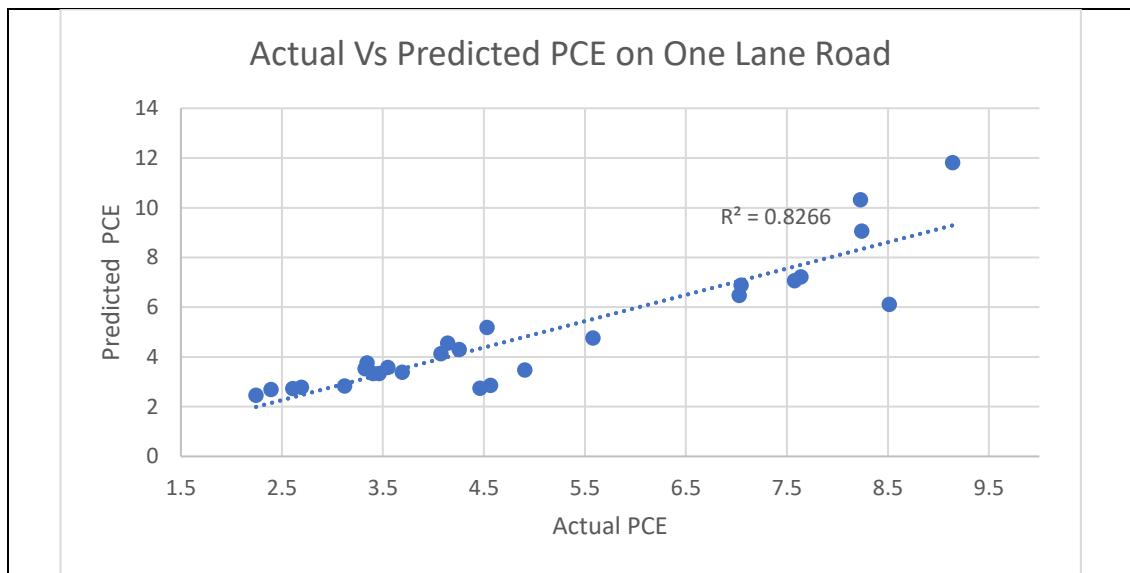


Fig 4.9 Validation results on a single lane

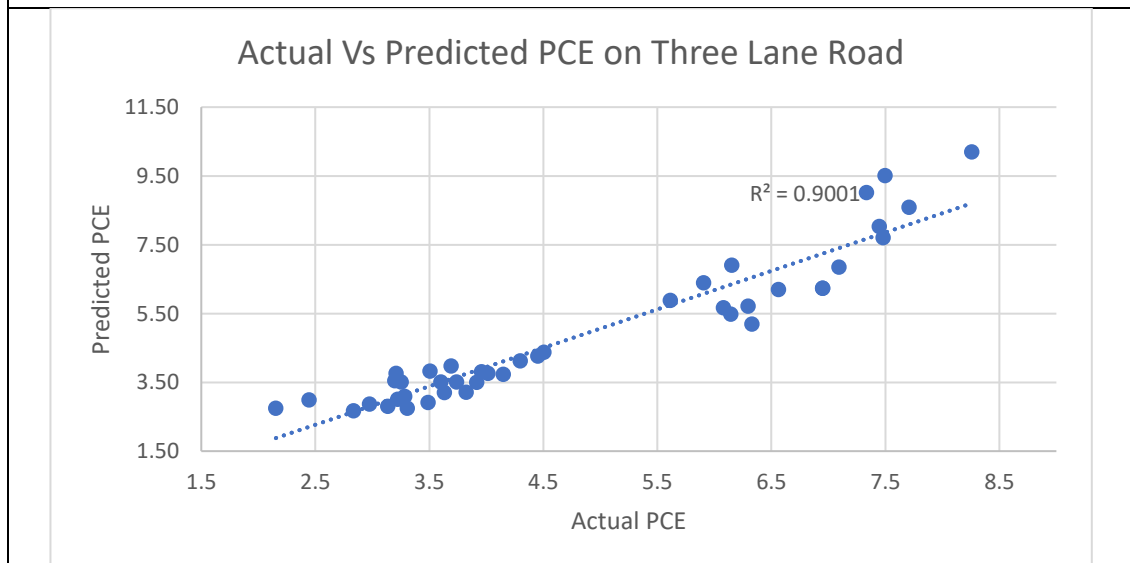
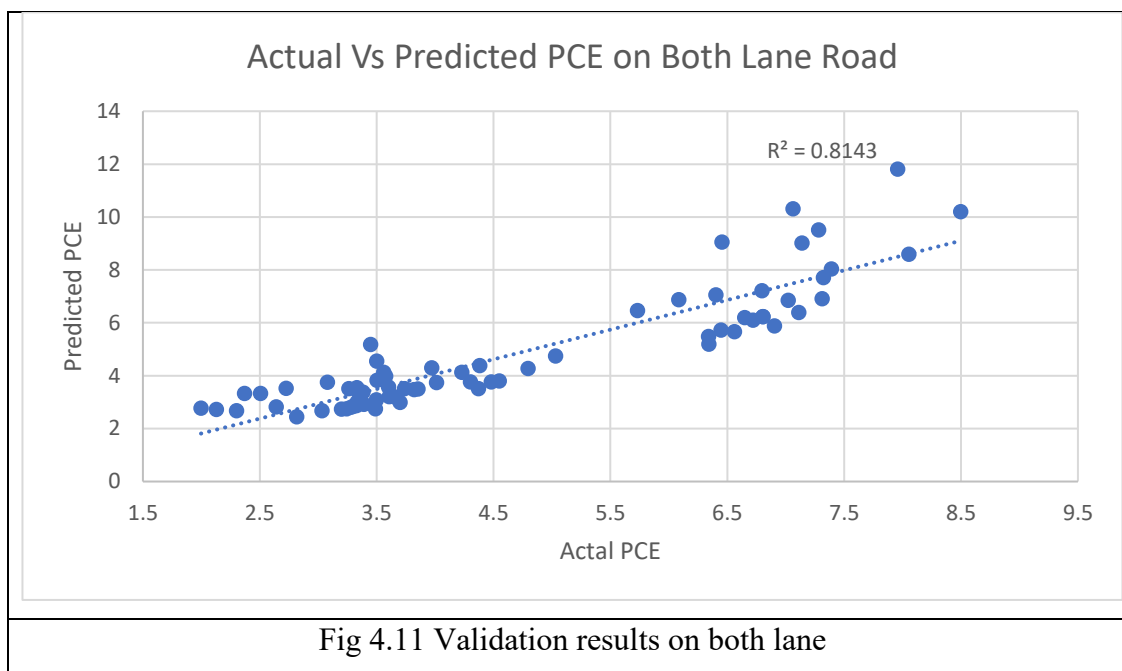


Fig 4.10 Validation results on three lanes



4.9 Passenger car equivalent Vs HCM 2010 manual

Table 4.28 Results of passenger car equivalence on 7.34 % grade Vs HCM 2010 manual

PCU obtained from the HCM 2010							
Upgrade (%)	Length(mil)	Percentage of truck & Buses					
		10					
>6	0-0.25	2.5					
PCU obtained from the recorded data							
Upgrade (%)	Length(mil)	Passenger car	Pickup/4WD	Minibus	Bus	Medium Truck	Heavy Truck
		Percentage (9.06)					
7.34	0.06	1.0	1.81	1.52	3.81	2.67	5.04

Research-Based PCE Values:

Research-based Passenger Car Unit (PCU) values have clear advantages compared to general results from Highway Capacity Manual (HCM). These values, tailored to the local traffic situation, accurately reflect the types of vehicles on the roads, road conditions (such as surface quality, maintenance) and how people drive. This accuracy helps design roads that really work for the traffic mix, improves how to manage traffic, and aligns policies with the specific traffic patterns. It's like having a precise tool that ensures the roads are well-prepared for emergencies which include factors like having clear emergency lanes, proper

signage and can handle traffic effectively. These specific values also assist in analyzing road capacity accurately, guiding decision-making with real data, and staying adaptable to changing traffic trends.

HCM PCE Values:

The general PCE values from the Highway Capacity Manual might not match the local traffic details. While these values are known, they might not guide this research well for roads that fit the unique traffic. Relying only on them could miss small traffic flow details, leading to less effective traffic management. The rules this research make with HCM PCE values might not match how traffic really works here. HCM values might not fully consider how different vehicles act in emergencies, making the emergency plans less effective. In practical terms, when there's an accident, the standard PCU value from HCM treats buses, motorcycles (MT), and heavy trucks (HT) as a single entity. As a result, it doesn't accurately reflect the number of individual cars affected by the incident. Also, they might not show how much traffic the roads can handle because they don't account for the local unique traffic factors.

5. CONCLUSION & RECOMMENDATION

5.1 Conclusion

The primary aim of this study is to ascertain passenger car unit values for various up-grade roads in Addis Ababa and review the impact of road grade and vehicle speed on PCE. Data encompassing speed, traffic volume, and geometrical aspects were collected through various means such as video cameras and manual equipment. Subsequently, relevant information, including traffic volume, traffic composition, and the 85th percentile speed, was extracted from the video footage. The dynamic PCU method was then employed to determine passenger car units for different upgrades along both one and three-lane roads. The findings from this analysis form the basis for the conclusions drawn in the subsequent sections.

- The traffic composition shows variations corresponding to changes in traffic volume. Particularly in Area 3 (Abem to Kotebe Kara), there is a noticeable distinction, marked by a significantly higher presence of buses (4.91%), medium trucks (6.68%), and heavy trucks (4.13%) compared to the remaining three segments.
- The initial road grade impacts the speed dynamics throughout the road segment. In a three-way segment, when the road grade initiates with a high grade, the speed pattern exhibits an inversely proportional relationship, starting high and concluding low. Likewise, in a one-way segment, the relationship remains inversely proportional, with speed commencing low and concluding high when the road starts with a high uphill grade.
- The road lane configuration significantly influences the Passenger Car Equivalence (PCE) along the entire road segment. In the uphill section, heavy vehicles tend to exhibit higher PCE values at both the beginning and end on one-lane roads compared to three-lane roads. Conversely, for buses and medium trucks, three-lane roads consistently demonstrate higher PCE values compared to one-lane roads at both the commencement and conclusion of the uphill stretch.
- The study shows distinct Passenger Car Unit (PCU) values for one-lane and three-lane upgrade roads at the end of the uphill stretch, with varying road grades for the selected road segments. For one-lane roads, at a 5.95% grade, PCU values stand at 3.3 for buses, 2.79 for Medium Trucks (MT), and 5.210 for Heavy Trucks (HT), while at a 7.45% grade, the values

are 3.19 for buses, 2.76 for MT, and 7.57 for HT. Conversely, on three-lane roads, the PCU values differ, recording 3.58 for buses, 3.67 for MT, and 5.34 for HT at a 7.68% grade, and 3.62 for buses, 2.59 for MT, and 7.28 for HT at an 8.69% grade for heavy trucks. These findings highlight the impact of road grade and lane configuration on PCU values.

- In conclusion, this study conducts a comparison between the Passenger Car Equivalence (PCE) values obtained in this research and those derived from the HCM 2010. The findings indicate significantly higher PCE values in the executed study, attributed to the consideration of local unique traffic conditions and geometrics, factors not accounted for in the HCM 2010. This emphasizes the importance of incorporating locally specific factors for a more accurate depiction of real traffic conditions in Addis Ababa, Ethiopia.

5.2 Recommendation

This research provides a recommendation for the following:

- Recommendation for Transport planning & Traffic regulation organizations
 - Consider conducting extensive research on passenger car equivalences with the aim of establishing a locally applicable standard factor. This factor can then be utilized to effectively address local conditions and requirements.
- Recommendation for future study
 - Utilize the trained MATLAB Code: The trained MATLAB code included in this study can be employed to predict vehicle speed which is the main feature to determine passenger car equivalence (PCE) values for new data.
 - Expand the input feature set in ANN, by incorporating additional input parameters beyond lane, vehicle type, and road grade like lane width, walkway width, and other relevant variables which can enhance the accuracy of ANN model and increase the model's capacity to capture complex relationships and make more accurate predictions regarding speed.
 - Incorporate Two- & Three-Wheel Vehicles: While this study primarily focused on vehicles with four wheels or more, future users can expand the analysis to include two-wheel vehicles like motorcycles. This extension would contribute to a comprehensive understanding of PCE across various vehicle categories, addressing a broader spectrum of road users.

6. REFERENCES







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7. APPENDIX

APPENDIX A - TRAFFIC COUNT OF THE STUDY AREAS

Time (1hr. Interval)													Total vehicle No.	Total flow
	PC	flow	Minibus	flow	Bus	flow	Pick up	flow	Medium truck	flow	Heavy truck	flow		
Ambo road to 18 mazoriya														
11:00 to 12:00	214	856	283	1132	23	92	105	420	29	116	8	32	662	2648
12:00 to 1:00	210	840	220	880	8	32	96	384	30	120	10	40	574	2296
1:00 to 2:00	270	1080	156	624	33	132	80	320	20	80	7	28	566	2264
2:00 to 3:00	223	892	239	956	31	124	82	328	17	68	6	24	598	2392
Gojam ber RR to Entoto														
11:00 to 12:00	150	600	131	524	14	56	96	384	10	40	18	72	419	1676
12:00 to 1:00	125	500	124	496	16	64	140	560	14	56	13	52	432	1728
1:00 to 2:00	131	524	136	544	17	68	157	628	6	24	24	96	471	1884
2:00 to 3:00	146	584	147	588	6	24	164	656	11	44	32	128	506	2024
Abem to kotebe kara														
11:00 to 12:00	230	920	76	304	16	64	41	164	25	100	26	104	414	1656
12:00 to 1:00	230	920	99	396	23	92	45	180	0	0	22	88	419	1676
1:00 to 2:00	292	1168	79	316	25	100	58	232	34	136	21	84	509	2036
2:00 to 3:00	273	1092	63	252	24	96	44	176	16	64	24	96	444	1776
Goro to jacros														

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11:00 to 12:00	613	2452	151	604	30	120	143	572	43	172	21	84	1001	4004
12:00 to 1:00	589	2356	109	436	43	172	114	456	41	164	41	164	937	3748
1:00 to 2:00	623	2492	139	556	40	160	144	576	61	244	38	152	1045	4180
2:00 to 3:00	724	2896	171	684	24	96	125	500	44	176	39	156	1127	4508

APPENDIX B – SAMPLE SPOT SPEED CALCULATION OF THE STUDY AREAS

No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)	No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)
Abem to Kara at grade 10.28%						Abem to Kara at grade 7.68%					
1	pc	33	43	10	36.00	1	pc	26	35	9	40.00
2	pick up	36	47	11	32.73	2	pick up	30	42	12	30.00
3	bus	40	51	11	32.73	3	bus	34	44	10	36.00
4	M truck	48	66	18	20.00	4	M truck	53	71	18	20.00
5	pc	50	66	16	22.50	5	pc	49	62	13	27.69
6	M truck	49	64	15	24.00	6	M truck	47	60	13	27.69
7	minibus	57	73	16	22.50	7	minibus	56	72	16	22.50
8	pc	61	75	14	25.71	8	pc	58	76	18	20.00
9	minibus	63	78	15	24.00	9	minibus	61	79	18	20.00
10	bus	71	85	14	25.71	10	bus	68	82	14	25.71
11	pc	74	89	15	24.00	11	pc	72	88	16	22.50
12	pc	74	92	18	20.00	12	pc	85	103	18	20.00
13	minibus	76	90	14	25.71	13	minibus	73	86	13	27.69
14	bus	116	129	13	27.69	14	bus	112	125	13	27.69
15	pc	132	140	8	45.00	15	pc	123	134	11	32.73
16	pc	137	148	11	32.73	16	pc	131	146	15	24.00
17	minibus	143	154	11	32.73	17	minibus	137	149	12	30.00
18	pick up	162	175	13	27.69	18	pick up	158	170	12	30.00
19	pc	167	179	12	30.00	19	pc	162	173	11	32.73
20	pc	180	190	10	36.00	20	pc	173	183	10	36.00
21	minibus	184	192	8	45.00	21	minibus	174	183	9	40.00
22	pc	191	206	15	24.00	22	pc	189	204	15	24.00
23	minibus	191	202	11	32.73	23	minibus	183	198	15	24.00

No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)	No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)
Ambo - 18 mazoriya at grade 1.80%						Ambo - 18 mazoriya at grade 7.34%					
1	H truck	39	54	15	24.00	1	H truck	45	55	10	36.00
2	Bus	44	57	13	27.69	2	Bus	48	62	14	25.71
3	Pc	46	59	13	27.69	3	Pc	50	65	15	24.00
4	Pc	49	62	13	27.69	4	Pc	53	67	14	25.71
5	Minibus	53	67	14	25.71	5	Minibus	58	68	10	36.00
6	Minibus	55	70	15	24.00	6	Minibus	61	73	12	30.00
7	M truck	57	72	15	24.00	7	M truck	63	75	12	30.00
8	Minibus	60	76	16	22.50	8	Minibus	67	80	13	27.69
9	Minibus	64	78	14	25.71	9	Minibus	69	86	17	21.18
10	Pc	78	92	14	25.71	10	Pc	77	92	15	24.00
11	Bus	86	97	11	32.73	11	Bus	88	103	15	24.00
12	Pc	191	210	19	18.95	12	Pc	125	137	12	30.00
13	Pc	234	248	14	25.71	13	Pc	238	250	12	30.00
14	Minibus	238	249	11	32.73	14	Minibus	240	253	13	27.69
15	H truck	312	331	19	18.95	15	H truck	328	342	14	25.71
16	Pick up	328	338	10	36.00	16	Pick up	347	361	14	25.71
17	Pc	353	365	12	30.00	17	Pc	356	367	11	32.73
18	Pc	382	394	12	30.00	18	Pc	385	399	14	25.71
19	Pick up	408	418	10	36.00	19	Pick up	404	416	12	30.00
20	Minibus	410	421	11	32.73	20	Minibus	412	423	11	32.73
21	Minibus	421	431	10	36.00	21	Minibus	422	433	11	32.73
22	Pc	435	444	9	40.00	22	Pc	431	442	11	32.73
23	Minibus	439	449	10	36.00	23	Minibus	435	447	12	30.00
24	Pc	454	472	18	20.00	24	Pc	458	470	12	30.00
25	Minibus	462	473	11	32.73	25	Minibus	462	472	10	36.00
26	M truck	488	499	11	32.73	26	M truck	490	502	12	30.00

	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)	No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)
Entoto Gojam ber at grade 4.04%						Entoto Gojam ber at grade 7.45%					
1	pc	6	15	9	40.00	1	pc	7	16	9	40.00
2	minibus	10	18	8	45.00	2	minibus	8	16	8	45.00
3	pc	9	17	8	45.00	3	pc	9	20	11	32.73
4	minibus	11	20	9	40.00	4	minibus	12	22	10	36.00
5	M truck	22	31	9	40.00	5	M truck	23	33	10	36.00
6	pick up	28	40	12	30.00	6	pick up	32	45	13	27.69
7	pc	53	61	8	45.00	7	pc	53	63	10	36.00
8	minibus	55	64	9	40.00	8	minibus	56	67	11	32.73
9	minibus	60	71	11	32.73	9	minibus	63	75	12	30.00
10	pc	64	75	11	32.73	10	pc	67	81	14	25.71
11	H truck	107	122	15	24.00	11	H truck	114	132	18	20.00
12	pc	115	124	9	40.00	12	pc	116	126	10	36.00
13	pc	118	127	9	40.00	13	pc	119	134	15	24.00
14	minibus	120	130	10	36.00	14	minibus	122	139	17	21.18
15	pc	133	144	11	32.73	15	pc	136	147	11	32.73
16	minibus	135	143	8	45.00	16	minibus	134	144	10	36.00
17	pick up	138	146	8	45.00	17	pick up	138	149	11	32.73
18	pc	140	149	9	40.00	18	pc	141	152	11	32.73
19	H truck	143	153	10	36.00	19	H truck	145	156	11	32.73
20	pc	146	158	12	30.00	20	pc	150	160	10	36.00
21	pc	149	159	10	36.00	21	pc	151	166	15	24.00
22	minibus	151	161	10	36.00	22	minibus	153	163	10	36.00
23	pick up	160	169	9	40.00	23	pick up	161	171	10	36.00

No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)	No	vehicle	Entry time (sec)	Exit time (second)	actual time	speed (km/hr)
Goro to jacros at grade 6.36%						Goro to jacros at grade 5.45%					
1	H truck	25	44	19	18.95	1	H truck	51	77	26	20.77
2	minibus	27	45	18	20.00	2	minibus	55	81	26	20.77
3	pc	60	78	18	20.00	3	pc	60	87	27	20.00
4	pc	61	76	15	24.00	4	pc	56	78	22	24.55
5	bus	65	83	18	20.00	5	bus	70	97	27	20.00
6	pc	75	92	17	21.18	6	pc	78	103	25	21.60
7	minibus	79	97	18	20.00	7	minibus	80	104	24	22.50
8	H truck	80	98	18	20.00	8	H truck	87	113	26	20.77
9	minibus	81	99	18	20.00	9	minibus	81	108	27	20.00
10	minibus	81	99	18	20.00	10	minibus	84	111	27	20.00
11	H truck	91	109	18	20.00	11	H truck	94	120	26	20.77
12	pc	94	111	17	21.18	12	pc	96	122	26	20.77
13	pc	97	115	18	20.00	13	pc	100	125	25	21.60
14	minibus	100	117	17	21.18	14	minibus	103	128	25	21.60
15	pc	102	119	17	21.18	15	pc	106	131	25	21.60
16	minibus	107	125	18	20.00	16	minibus	107	131	24	22.50
17	pickup	118	135	17	21.18	17	pickup	116	141	25	21.60
18	pickup	122	139	17	21.18	18	pickup	119	142	23	23.48
19	pc	124	140	16	22.50	19	pc	121	145	24	22.50
20	pc	130	146	16	22.50	20	pc	126	150	24	22.50
21	pc	133	150	17	21.18	21	pc	130	154	24	22.50
22	pc	136	151	15	24.00	22	pc	132	155	23	23.48
23	pickup	140	157	17	21.18	23	pickup	133	156	23	23.48

APPENDIX C – INPUT AND OUTPUT DATA FOR ANN

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
1	0	0.1028	3	36.00	363	4	0.0292	1	45.00	725	0	0.0545	3	28.42
2	1	0.1028	3	32.73	364	1	0.0292	1	45.00	726	1	0.0545	3	22.50
3	3	0.1028	3	32.73	365	5	0.0292	1	40.00	727	5	0.0545	3	20.77
4	4	0.1028	3	20.00	366	1	0.0292	1	45.00	728	1	0.0545	3	24.55
5	0	0.1028	3	22.50	367	4	0.0292	1	32.73	729	4	0.0545	3	23.48
6	4	0.1028	3	24.00	368	2	0.0292	1	40.00	730	0	0.0545	3	31.76
7	2	0.1028	3	22.50	369	2	0.0292	1	40.00	731	2	0.0545	3	28.42
8	0	0.1028	3	25.71	370	0	0.0292	1	45.00	732	5	0.0545	3	22.50
9	2	0.1028	3	24.00	371	0	0.0292	1	45.00	733	5	0.0545	3	23.48
10	3	0.1028	3	25.71	372	2	0.0292	1	32.73	734	0	0.0545	3	24.55
11	0	0.1028	3	24.00	373	5	0.0292	1	32.73	735	1	0.0545	3	23.48
12	0	0.1028	3	20.00	374	2	0.0292	1	40.00	736	1	0.0545	3	25.71
13	2	0.1028	3	25.71	375	0	0.0292	1	45.00	737	1	0.0545	3	27.00
14	3	0.1028	3	27.69	376	4	0.0292	1	45.00	738	0	0.0545	3	23.48
15	0	0.1028	3	45.00	377	0	0.0292	1	45.00	739	1	0.0545	3	23.48
16	0	0.1028	3	32.73	378	2	0.0292	1	40.00	740	1	0.0545	3	23.48
17	2	0.1028	3	32.73	379	4	0.0292	1	36.00	741	5	0.0545	3	33.75
18	1	0.1028	3	27.69	380	2	0.0292	1	45.00	742	2	0.0545	3	28.42
19	0	0.1028	3	30.00	381	1	0.0292	1	40.00	743	0	0.0545	3	21.60

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
20	0	0.1028	3	36.00	382	2	0.0292	1	45.00	744	5	0.0364	3	23.48
21	2	0.1028	3	45.00	383	2	0.0292	1	45.00	745	2	0.0364	3	22.50
22	0	0.1028	3	24.00	384	4	0.0292	1	22.50	746	1	0.0364	3	22.50
23	2	0.1028	3	32.73	385	3	0.0292	1	36.00	747	0	0.0364	3	24.55
24	1	0.1028	3	30.00	386	3	0.0292	1	32.73	748	3	0.0364	3	19.29
25	4	0.1028	3	24.00	387	3	0.0292	1	24.00	749	0	0.0364	3	23.48
26	0	0.1028	3	36.00	388	3	0.0292	1	30.00	750	2	0.0364	3	20.77
27	2	0.1028	3	45.00	389	3	0.0292	1	27.69	751	5	0.0364	3	20.77
28	0	0.1028	3	30.00	390	0	0.0404	1	40.00	752	2	0.0364	3	20.77
29	2	0.1028	3	30.00	391	2	0.0404	1	45.00	753	2	0.0364	3	22.50
30	4	0.1028	3	30.00	392	0	0.0404	1	45.00	754	5	0.0364	3	21.60
31	3	0.1028	3	30.00	393	2	0.0404	1	40.00	755	0	0.0364	3	20.77
32	0	0.1028	3	32.73	394	4	0.0404	1	40.00	756	0	0.0364	3	20.00
33	0	0.1028	3	27.69	395	1	0.0404	1	30.00	757	2	0.0364	3	21.60
34	2	0.1028	3	32.73	396	0	0.0404	1	45.00	758	0	0.0364	3	20.77
35	0	0.1028	3	30.00	397	2	0.0404	1	40.00	759	2	0.0364	3	21.60
36	2	0.1028	3	20.00	398	2	0.0404	1	32.73	760	1	0.0364	3	20.00
37	0	0.1028	3	20.00	399	0	0.0404	1	32.73	761	1	0.0364	3	21.60
38	4	0.1028	3	21.18	400	5	0.0404	1	24.00	762	1	0.0364	3	21.60
39	5	0.1028	3	18.95	401	0	0.0404	1	40.00	763	0	0.0364	3	20.77

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
40	0	0.1028	3	22.50	402	0	0.0404	1	40.00	764	0	0.0364	3	21.60
41	0	0.1028	3	32.73	403	2	0.0404	1	36.00	765	0	0.0364	3	20.77
42	5	0.1028	3	18.95	404	0	0.0404	1	32.73	766	1	0.0364	3	22.50
43	0	0.1028	3	27.69	405	2	0.0404	1	45.00	767	0	0.0364	3	22.50
44	2	0.1028	3	27.69	406	1	0.0404	1	45.00	768	0	0.0364	3	22.50
45	2	0.1028	3	36.00	407	0	0.0404	1	40.00	769	1	0.0364	3	23.48
46	1	0.1028	3	40.00	408	5	0.0404	1	36.00	770	1	0.0364	3	23.48
47	0	0.1028	3	30.00	409	0	0.0404	1	30.00	771	2	0.0364	3	27.00
48	1	0.1028	3	27.69	410	0	0.0404	1	36.00	772	4	0.0364	3	25.71
49	2	0.1028	3	36.00	411	2	0.0404	1	36.00	773	0	0.0364	3	27.00
50	4	0.1028	3	18.95	412	1	0.0404	1	40.00	774	1	0.0364	3	27.00
51	2	0.1028	3	36.00	413	4	0.0404	1	40.00	775	4	0.0364	3	25.71
52	1	0.1028	3	40.00	414	2	0.0404	1	45.00	776	4	0.0364	3	20.77
53	2	0.1028	3	40.00	415	0	0.0404	1	36.00	777	1	0.0364	3	24.55
54	0	0.1028	3	30.00	416	0	0.0404	1	36.00	778	0	0.0364	3	22.50
55	0	0.1028	3	36.00	417	2	0.0404	1	32.73	779	0	0.0364	3	23.48
56	0	0.1028	3	30.00	418	2	0.0404	1	45.00	780	2	0.0364	3	22.50
57	1	0.1028	3	27.69	419	4	0.0404	1	22.50	781	0	0.0364	3	22.50
58	3	0.1028	3	27.69	420	2	0.0404	1	30.00	782	0	0.0364	3	23.48
59	0	0.1028	3	27.69	421	2	0.0404	1	40.00	783	4	0.0364	3	23.48

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
60	0	0.1028	3	30.00	422	2	0.0404	1	45.00	784	5	0.0364	3	20.00
61	0	0.1028	3	25.71	423	2	0.0404	1	45.00	785	5	0.0364	3	24.55
62	2	0.1028	3	24.00	424	0	0.0404	1	45.00	786	5	0.0364	3	27.00
63	5	0.1028	3	20.00	425	0	0.0404	1	45.00	787	0	0.0364	3	27.00
64	5	0.1028	3	36.00	426	0	0.0404	1	40.00	788	1	0.0364	3	25.71
65	3	0.1028	3	27.69	427	0	0.0404	1	45.00	789	0	0.0364	3	27.00
66	3	0.1028	3	30.00	428	0	0.0404	1	40.00	790	2	0.0364	3	23.48
67	5	0.1028	3	22.50	429	0	0.0404	1	45.00	791	0	0.0364	3	27.00
68	0	0.0768	3	40.00	430	0	0.0404	1	30.00	792	0	0.0364	3	22.50
69	1	0.0768	3	30.00	431	0	0.0404	1	45.00	793	2	0.0364	3	30.00
70	3	0.0768	3	36.00	432	1	0.0404	1	45.00	794	3	0.0364	3	20.00
71	4	0.0768	3	20.00	433	2	0.0404	1	45.00	795	1	0.0364	3	18.62
72	0	0.0768	3	27.69	434	0	0.0404	1	45.00	796	1	0.0364	3	20.77
73	4	0.0768	3	27.69	435	0	0.0404	1	45.00	797	5	0.0364	3	23.48
74	2	0.0768	3	22.50	436	2	0.0404	1	45.00	798	5	0.0364	3	21.60
75	0	0.0768	3	20.00	437	2	0.0404	1	45.00	799	1	0.0364	3	23.48
76	2	0.0768	3	20.00	438	0	0.0404	1	45.00	800	5	0.0364	3	20.00
77	3	0.0768	3	25.71	439	5	0.0404	1	32.73	801	2	0.0364	3	20.00
78	0	0.0768	3	22.50	440	1	0.0404	1	45.00	802	4	0.0364	3	23.48
79	0	0.0768	3	20.00	441	2	0.0404	1	45.00	803	2	0.0364	3	23.48

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
80	2	0.0768	3	27.69	442	5	0.0404	1	25.71	804	2	0.0364	3	20.00
81	3	0.0768	3	27.69	443	5	0.0404	1	22.50	805	4	0.0364	3	21.60
82	0	0.0768	3	32.73	444	4	0.0404	1	20.00	806	4	0.0364	3	21.60
83	0	0.0768	3	24.00	445	4	0.0404	1	32.73	807	0	0.0364	3	21.60
84	2	0.0768	3	30.00	446	4	0.0404	1	45.00	808	1	0.0364	3	20.77
85	1	0.0768	3	30.00	447	4	0.0404	1	40.00	809	1	0.0364	3	20.00
86	0	0.0768	3	32.73	448	4	0.0404	1	45.00	810	0	0.0364	3	20.77
87	0	0.0768	3	36.00	449	4	0.0404	1	36.00	811	1	0.0364	3	21.60
88	2	0.0768	3	40.00	450	4	0.0404	1	32.73	812	0	0.0364	3	22.50
89	0	0.0768	3	24.00	451	5	0.0404	1	36.00	813	0	0.0364	3	22.50
90	2	0.0768	3	24.00	452	5	0.0404	1	40.00	814	2	0.0364	3	24.55
91	1	0.0768	3	30.00	453	3	0.0404	1	40.00	815	1	0.0364	3	27.00
92	4	0.0768	3	24.00	454	3	0.0404	1	36.00	816	5	0.0364	3	20.00
93	0	0.0768	3	36.00	455	3	0.0404	1	27.69	817	1	0.0364	3	20.00
94	2	0.0768	3	40.00	456	0	0.0745	1	40.00	818	0	0.0364	3	24.55
95	0	0.0768	3	30.00	457	2	0.0745	1	45.00	819	1	0.0364	3	20.00
96	2	0.0768	3	27.69	458	0	0.0745	1	32.73	820	0	0.0364	3	23.48
97	4	0.0768	3	24.00	459	2	0.0745	1	36.00	821	4	0.0364	3	21.60
98	3	0.0768	3	30.00	460	4	0.0745	1	36.00	822	0	0.0364	3	22.50
99	0	0.0768	3	30.00	461	1	0.0745	1	27.69	823	1	0.0364	3	22.50

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
100	0	0.0768	3	25.71	462	0	0.0745	1	36.00	824	1	0.0364	3	20.77
101	2	0.0768	3	36.00	463	2	0.0745	1	32.73	825	0	0.0364	3	20.77
102	0	0.0768	3	20.00	464	2	0.0745	1	30.00	826	2	0.0364	3	20.77
103	2	0.0768	3	20.00	465	0	0.0745	1	25.71	827	3	0.0364	3	20.00
104	0	0.0768	3	27.69	466	5	0.0745	1	20.00	828	1	0.0364	3	22.50
105	4	0.0768	3	21.18	467	0	0.0745	1	36.00	829	5	0.0364	3	23.48
106	5	0.0768	3	20.00	468	0	0.0745	1	24.00	830	2	0.0364	3	23.48
107	0	0.0768	3	24.00	469	2	0.0745	1	21.18	831	4	0.0364	3	24.55
108	0	0.0768	3	32.73	470	0	0.0745	1	32.73	832	1	0.0364	3	22.50
109	5	0.0768	3	20.00	471	2	0.0745	1	36.00	833	0	0.0364	3	20.77
110	0	0.0768	3	32.73	472	1	0.0745	1	32.73	834	5	0.0364	3	20.77
111	2	0.0768	3	32.73	473	0	0.0745	1	32.73	835	1	0.0364	3	28.42
112	2	0.0768	3	27.69	474	5	0.0745	1	32.73	836	0	0.0364	3	27.00
113	1	0.0768	3	30.00	475	0	0.0745	1	36.00	837	1	0.0364	3	23.48
114	0	0.0768	3	25.71	476	0	0.0745	1	24.00	838	5	0.0364	3	21.60
115	1	0.0768	3	22.50	477	2	0.0745	1	36.00	839	1	0.0364	3	19.29
116	2	0.0768	3	30.00	478	1	0.0745	1	36.00	840	4	0.0364	3	24.55
117	4	0.0768	3	18.95	479	4	0.0745	1	36.00	841	0	0.0364	3	33.75
118	2	0.0768	3	40.00	480	2	0.0745	1	36.00	842	2	0.0364	3	27.00
119	1	0.0768	3	45.00	481	0	0.0745	1	40.00	843	5	0.0364	3	25.71

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
120	2	0.0768	3	40.00	482	0	0.0745	1	36.00	844	5	0.0364	3	24.55
121	0	0.0768	3	30.00	483	2	0.0745	1	36.00	845	0	0.0364	3	27.00
122	0	0.0768	3	32.73	484	2	0.0745	1	45.00	846	1	0.0364	3	27.00
123	0	0.0768	3	27.69	485	4	0.0745	1	21.18	847	1	0.0364	3	25.71
124	1	0.0768	3	25.71	486	2	0.0745	1	45.00	848	1	0.0364	3	27.00
125	3	0.0768	3	21.18	487	2	0.0745	1	45.00	849	0	0.0364	3	24.55
126	0	0.0768	3	24.00	488	2	0.0745	1	36.00	850	1	0.0364	3	24.55
127	0	0.0768	3	24.00	489	2	0.0745	1	22.50	851	1	0.0364	3	25.71
128	0	0.0768	3	22.50	490	0	0.0745	1	25.71	852	5	0.0364	3	20.77
129	2	0.0768	3	27.69	491	0	0.0745	1	40.00	853	2	0.0364	3	28.42
130	5	0.0768	3	18.95	492	0	0.0745	1	30.00	854	0	0.0364	3	22.50
131	5	0.0768	3	36.00	493	0	0.0745	1	30.00	855	0	0.0869	3	24.00
132	3	0.0768	3	27.69	494	0	0.0745	1	30.00	856	2	0.0869	3	21.18
133	3	0.0768	3	25.71	495	0	0.0745	1	30.00	857	0	0.0869	3	27.69
134	5	0.0768	3	20.00	496	0	0.0745	1	30.00	858	5	0.0869	3	22.50
135	5	0.0734	1	36.00	497	0	0.0745	1	27.69	859	1	0.0869	3	32.73
136	3	0.0734	1	25.71	498	1	0.0745	1	27.69	860	0	0.0869	3	21.18
137	0	0.0734	1	24.00	499	2	0.0745	1	36.00	861	5	0.0869	3	15.65
138	0	0.0734	1	25.71	500	0	0.0745	1	36.00	862	0	0.0869	3	30.00
139	2	0.0734	1	36.00	501	0	0.0745	1	40.00	863	0	0.0869	3	27.69

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
140	2	0.0734	1	30.00	502	2	0.0745	1	45.00	864	0	0.0869	3	25.71
141	4	0.0734	1	30.00	503	2	0.0745	1	36.00	865	2	0.0869	3	27.69
142	2	0.0734	1	27.69	504	0	0.0745	1	45.00	866	0	0.0869	3	27.69
143	2	0.0734	1	21.18	505	5	0.0745	1	30.00	867	5	0.0869	3	30.00
144	0	0.0734	1	24.00	506	1	0.0745	1	45.00	868	0	0.0869	3	21.18
145	3	0.0734	1	24.00	507	2	0.0745	1	45.00	869	0	0.0869	3	24.00
146	0	0.0734	1	30.00	508	5	0.0745	1	30.00	870	0	0.0869	3	24.00
147	0	0.0734	1	30.00	509	5	0.0745	1	20.00	871	0	0.0869	3	21.18
148	2	0.0734	1	27.69	510	4	0.0745	1	30.00	872	0	0.0869	3	20.00
149	5	0.0734	1	25.71	511	4	0.0745	1	36.00	873	0	0.0869	3	20.00
150	1	0.0734	1	25.71	512	4	0.0745	1	21.18	874	0	0.0869	3	22.50
151	0	0.0734	1	32.73	513	4	0.0745	1	21.18	875	2	0.0869	3	21.18
152	0	0.0734	1	25.71	514	4	0.0745	1	22.50	876	0	0.0869	3	22.50
153	1	0.0734	1	30.00	515	4	0.0745	1	30.00	877	0	0.0869	3	24.00
154	2	0.0734	1	32.73	516	4	0.0745	1	32.73	878	0	0.0869	3	21.18
155	2	0.0734	1	32.73	517	5	0.0745	1	25.71	879	0	0.0869	3	32.73
156	0	0.0734	1	32.73	518	5	0.0745	1	27.69	880	2	0.0869	3	27.69
157	2	0.0734	1	30.00	519	3	0.0745	1	32.73	881	5	0.0869	3	30.00
158	0	0.0734	1	30.00	520	3	0.0745	1	30.00	882	4	0.0869	3	30.00
159	2	0.0734	1	36.00	521	3	0.0745	1	40.00	883	1	0.0869	3	32.73

APPENDIX H – TRAINED MATLAB CODE TO PREDICT VEHICLE SPEED

```
% Solve an Input-Output Fitting problem with a Neural Network
% Script generated by Neural Fitting app
```

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
160	4	0.0734	1	30.00	522	5	0.0636	3	18.95	884	0	0.0869	3	32.73
161	0	0.0734	1	32.73	523	2	0.0636	3	20.00	885	2	0.0869	3	32.73
162	2	0.0734	1	25.71	524	1	0.0636	3	20.00	886	0	0.0869	3	30.00
163	0	0.0734	1	30.00	525	0	0.0636	3	24.00	887	0	0.0869	3	32.73
164	2	0.0734	1	32.73	526	3	0.0636	3	20.00	888	2	0.0869	3	36.00
165	0	0.0734	1	27.69	527	0	0.0636	3	21.18	889	1	0.0869	3	32.73
166	0	0.0734	1	32.73	528	2	0.0636	3	20.00	890	1	0.0869	3	32.73
167	2	0.0734	1	40.00	529	5	0.0636	3	20.00	891	5	0.0869	3	24.00
168	0	0.0734	1	32.73	530	2	0.0636	3	20.00	892	2	0.0869	3	36.00
169	0	0.0734	1	40.00	531	2	0.0636	3	20.00	893	0	0.0869	3	36.00
170	0	0.0734	1	36.00	532	5	0.0636	3	20.00	894	3	0.0869	3	27.69
171	1	0.0734	1	27.69	533	0	0.0636	3	21.18	895	2	0.0869	3	36.00
172	0	0.0734	1	30.00	534	0	0.0636	3	20.00	896	4	0.0869	3	25.71
173	2	0.0734	1	24.00	535	2	0.0636	3	21.18	897	2	0.0869	3	30.00
174	2	0.0734	1	24.00	536	0	0.0636	3	21.18	898	1	0.0869	3	30.00
175	0	0.0734	1	25.71	537	2	0.0636	3	20.00	899	1	0.0869	3	27.69
176	2	0.0734	1	30.00	538	1	0.0636	3	21.18	900	0	0.0869	3	27.69
177	2	0.0734	1	27.69	539	1	0.0636	3	21.18	901	2	0.0869	3	27.69
178	2	0.0734	1	22.50	540	1	0.0636	3	22.50	902	0	0.0869	3	30.00
179	2	0.0588	1	21.13	541	0	0.0636	3	22.50	903	4	0.0869	3	25.71

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
180	2	0.0588	1	21.13	542	0	0.0636	3	21.18	904	1	0.0869	3	30.00
181	2	0.0588	1	18.69	543	0	0.0636	3	24.00	905	2	0.0869	3	24.00
182	1	0.0588	1	18.69	544	1	0.0636	3	21.18	906	2	0.0869	3	30.00
183	4	0.0588	1	21.13	545	0	0.0636	3	24.00	907	1	0.0869	3	25.71
184	1	0.0588	1	22.09	546	0	0.0636	3	24.00	908	0	0.0869	3	20.00
185	2	0.0588	1	23.14	547	1	0.0636	3	24.00	909	0	0.0869	3	25.71
186	1	0.0588	1	20.25	548	1	0.0636	3	21.18	910	2	0.0869	3	32.73
187	5	0.0588	1	20.25	549	2	0.0636	3	21.18	911	0	0.0869	3	36.00
188	2	0.0588	1	22.09	550	4	0.0636	3	21.18	912	1	0.0869	3	32.73
189	0	0.0588	1	21.13	551	0	0.0636	3	22.50	913	1	0.0869	3	36.00
190	2	0.0588	1	20.25	552	1	0.0636	3	21.18	914	0	0.0869	3	27.69
191	4	0.0588	1	20.25	553	4	0.0636	3	21.18	915	1	0.0869	3	30.00
192	1	0.0588	1	23.14	554	4	0.0636	3	20.00	916	0	0.0869	3	45.00
193	4	0.0588	1	23.14	555	1	0.0636	3	20.00	917	0	0.0869	3	36.00
194	1	0.0588	1	22.09	556	0	0.0636	3	20.00	918	2	0.0869	3	40.00
195	0	0.0588	1	24.30	557	0	0.0636	3	21.18	919	4	0.0869	3	40.00
196	2	0.0588	1	20.25	558	2	0.0636	3	22.50	920	2	0.0869	3	40.00
197	2	0.0588	1	20.25	559	0	0.0636	3	21.18	921	2	0.0869	3	21.18
198	1	0.0588	1	20.25	560	0	0.0636	3	22.50	922	0	0.0869	3	25.71
199	0	0.0588	1	24.30	561	4	0.0636	3	20.00	923	2	0.0869	3	27.69

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
200	2	0.0588	1	21.13	562	5	0.0636	3	20.00	924	0	0.0869	3	30.00
201	2	0.0588	1	24.30	563	5	0.0636	3	24.00	925	0	0.0869	3	30.00
202	2	0.0588	1	21.13	564	5	0.0636	3	20.00	926	1	0.0869	3	32.73
203	0	0.0588	1	20.25	565	0	0.0636	3	20.00	927	4	0.0869	3	32.73
204	0	0.0588	1	22.09	566	1	0.0636	3	20.00	928	2	0.0869	3	32.73
205	2	0.0588	1	23.14	567	0	0.0636	3	20.00	929	3	0.0869	3	20.00
206	2	0.0588	1	24.30	568	2	0.0636	3	21.18	930	0	0.0869	3	30.00
207	4	0.0588	1	20.25	569	0	0.0636	3	21.18	931	1	0.0869	3	27.69
208	2	0.0588	1	20.25	570	0	0.0636	3	20.00	932	2	0.0869	3	32.73
209	0	0.0588	1	22.09	571	2	0.0636	3	21.18	933	0	0.0869	3	30.00
210	4	0.0588	1	24.30	572	3	0.0636	3	21.18	934	1	0.0869	3	24.00
211	2	0.0588	1	21.13	573	1	0.0636	3	20.00	935	0	0.0869	3	32.73
212	0	0.0588	1	20.25	574	1	0.0636	3	21.18	936	1	0.0869	3	25.71
213	0	0.0588	1	24.30	575	5	0.0636	3	20.00	937	4	0.0869	3	21.18
214	0	0.0588	1	23.14	576	5	0.0636	3	20.00	938	0	0.0869	3	24.00
215	2	0.0588	1	24.30	577	1	0.0636	3	21.18	939	2	0.0869	3	30.00
216	0	0.0588	1	24.30	578	5	0.0636	3	20.00	940	1	0.0869	3	27.69
217	2	0.0588	1	22.09	579	2	0.0636	3	20.00	941	0	0.0869	3	30.00
218	2	0.0588	1	24.30	580	4	0.0636	3	20.00	942	1	0.0869	3	40.00
219	2	0.0588	1	24.30	581	2	0.0636	3	20.00	943	0	0.0869	3	27.69

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
220	0	0.0588	1	23.14	582	2	0.0636	3	21.18	944	1	0.0869	3	30.00
221	1	0.0588	1	24.30	583	4	0.0636	3	21.18	945	2	0.0869	3	36.00
222	2	0.0588	1	24.30	584	4	0.0636	3	21.18	946	2	0.0869	3	40.00
223	0	0.0588	1	22.09	585	0	0.0636	3	24.00	947	4	0.0869	3	27.69
224	2	0.0588	1	21.13	586	1	0.0636	3	24.00	948	2	0.0869	3	32.73
225	0	0.0588	1	21.13	587	1	0.0636	3	22.50	949	1	0.0869	3	25.71
226	3	0.0588	1	23.14	588	0	0.0636	3	22.50	950	2	0.0869	3	32.73
227	0	0.0588	1	24.30	589	1	0.0636	3	20.00	951	0	0.0869	3	30.00
228	0	0.0588	1	21.13	590	0	0.0636	3	20.00	952	1	0.0869	3	25.71
229	2	0.0588	1	21.13	591	0	0.0636	3	22.50	953	1	0.0869	3	32.73
230	0	0.0588	1	22.09	592	2	0.0636	3	24.00	954	3	0.0869	3	22.50
231	1	0.0588	1	21.13	593	1	0.0636	3	22.50	955	5	0.0869	3	20.00
232	2	0.0588	1	23.14	594	5	0.0636	3	20.00	956	1	0.0869	3	30.00
233	0	0.0588	1	22.09	595	1	0.0636	3	21.18	957	5	0.0869	3	24.00
234	2	0.0588	1	20.25	596	0	0.0636	3	22.50	958	1	0.0869	3	21.18
235	2	0.0588	1	22.09	597	1	0.0636	3	22.50	959	2	0.0869	3	32.73
236	2	0.0588	1	21.13	598	0	0.0636	3	24.00	960	5	0.0869	3	21.18
237	0	0.0588	1	20.25	599	4	0.0636	3	20.00	961	5	0.0869	3	21.18
238	0	0.0588	1	19.44	600	0	0.0636	3	20.00	962	1	0.0869	3	22.50
239	2	0.0588	1	24.30	601	1	0.0636	3	21.18	963	3	0.0869	3	21.18

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No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
240	5	0.0588	1	20.25	602	1	0.0636	3	20.00	964	4	0.0869	3	22.50
241	2	0.0588	1	19.44	603	0	0.0636	3	22.50	965	5	0.0869	3	24.00
242	2	0.0588	1	20.25	604	2	0.0636	3	20.00	966	5	0.0869	3	21.18
243	0	0.0588	1	19.44	605	3	0.0636	3	22.50	967	3	0.0869	3	25.71
244	5	0.0588	1	21.13	606	1	0.0636	3	20.00	968	1	0.0869	3	30.00
245	1	0.0588	1	19.44	607	5	0.0636	3	20.00	969	4	0.0869	3	24.00
246	3	0.0588	1	19.44	608	2	0.0636	3	20.00	970	0	0.0869	3	30.00
247	2	0.0588	1	19.44	609	4	0.0636	3	21.18	971	0	0.0818	3	25.71
248	0	0.0588	1	20.25	610	1	0.0636	3	20.00	972	2	0.0818	3	22.50
249	0	0.0588	1	20.25	611	0	0.0636	3	21.18	973	0	0.0818	3	22.50
250	2	0.0588	1	20.25	612	5	0.0636	3	20.00	974	5	0.0818	3	22.50
251	0	0.0588	1	19.44	613	1	0.0636	3	20.00	975	1	0.0818	3	21.18
252	2	0.0588	1	20.25	614	0	0.0636	3	25.71	976	0	0.0818	3	25.71
253	2	0.0588	1	20.25	615	1	0.0636	3	22.50	977	5	0.0818	3	20.00
254	3	0.0588	1	19.44	616	5	0.0636	3	24.00	978	0	0.0818	3	24.00
255	2	0.0588	1	20.25	617	1	0.0636	3	27.69	979	0	0.0818	3	25.71
256	2	0.0588	1	19.44	618	4	0.0636	3	21.18	980	0	0.0818	3	27.69
257	2	0.0588	1	19.44	619	0	0.0636	3	32.73	981	2	0.0818	3	24.00
258	0	0.0588	1	20.25	620	2	0.0636	3	21.18	982	0	0.0818	3	20.00
259	2	0.0588	1	19.44	621	5	0.0636	3	24.00	983	5	0.0818	3	22.50

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
260	2	0.0588	1	23.14	622	5	0.0636	3	22.50	984	0	0.0818	3	30.00
261	2	0.0588	1	22.09	623	0	0.0636	3	21.18	985	0	0.0818	3	25.71
262	0	0.0588	1	21.13	624	1	0.0636	3	22.50	986	0	0.0818	3	20.00
263	4	0.0588	1	21.13	625	1	0.0636	3	25.71	987	0	0.0818	3	21.18
264	1	0.0588	1	22.09	626	1	0.0636	3	24.00	988	0	0.0818	3	20.00
265	0	0.0588	1	21.13	627	0	0.0636	3	22.50	989	0	0.0818	3	20.00
266	2	0.0588	1	25.58	628	1	0.0636	3	21.18	990	0	0.0818	3	22.50
267	2	0.0588	1	20.25	629	1	0.0636	3	22.50	991	2	0.0818	3	22.50
268	2	0.0588	1	21.13	630	5	0.0636	3	20.00	992	0	0.0818	3	20.00
269	1	0.0588	1	22.09	631	2	0.0636	3	24.00	993	0	0.0818	3	25.71
270	0	0.0588	1	22.09	632	0	0.0636	3	20.00	994	0	0.0818	3	22.50
271	0	0.0588	1	20.25	633	5	0.0545	3	20.77	995	0	0.0818	3	25.71
272	0	0.0588	1	20.25	634	2	0.0545	3	20.77	996	2	0.0818	3	22.50
273	2	0.0588	1	19.44	635	1	0.0545	3	20.00	997	5	0.0818	3	25.71
274	2	0.0588	1	19.44	636	0	0.0545	3	24.55	998	4	0.0818	3	30.00
275	0	0.0588	1	20.25	637	3	0.0545	3	20.00	999	1	0.0818	3	30.00
276	0	0.0595	1	36.00	638	0	0.0545	3	21.60	1000	0	0.0818	3	30.00
277	0	0.0595	1	36.00	639	2	0.0545	3	22.50	1001	2	0.0818	3	27.69
278	0	0.0595	1	36.00	640	5	0.0545	3	20.77	1002	0	0.0818	3	27.69
279	2	0.0595	1	36.00	641	2	0.0545	3	20.00	1003	0	0.0818	3	27.69

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
280	0	0.0595	1	36.00	642	2	0.0545	3	20.00	1004	2	0.0818	3	24.00
281	3	0.0595	1	22.50	643	5	0.0545	3	20.77	1005	1	0.0818	3	36.00
282	2	0.0595	1	36.00	644	0	0.0545	3	20.77	1006	1	0.0818	3	25.71
283	4	0.0595	1	36.00	645	0	0.0545	3	21.60	1007	5	0.0818	3	22.50
284	0	0.0595	1	45.00	646	2	0.0545	3	21.60	1008	2	0.0818	3	36.00
285	2	0.0595	1	30.00	647	0	0.0545	3	21.60	1009	0	0.0818	3	36.00
286	2	0.0595	1	20.00	648	2	0.0545	3	22.50	1010	3	0.0818	3	22.50
287	2	0.0595	1	22.50	649	1	0.0545	3	21.60	1011	2	0.0818	3	36.00
288	4	0.0595	1	25.71	650	1	0.0545	3	23.48	1012	4	0.0818	3	25.71
289	0	0.0595	1	25.71	651	1	0.0545	3	22.50	1013	2	0.0818	3	24.00
290	2	0.0595	1	30.00	652	0	0.0545	3	22.50	1014	1	0.0818	3	25.71
291	2	0.0595	1	45.00	653	0	0.0545	3	22.50	1015	1	0.0818	3	25.71
292	2	0.0595	1	45.00	654	0	0.0545	3	23.48	1016	0	0.0818	3	24.00
293	0	0.0595	1	45.00	655	1	0.0545	3	23.48	1017	2	0.0818	3	24.00
294	0	0.0595	1	30.00	656	0	0.0545	3	19.29	1018	0	0.0818	3	27.69
295	4	0.0595	1	36.00	657	0	0.0545	3	20.00	1019	4	0.0818	3	24.00
296	0	0.0595	1	30.00	658	1	0.0545	3	20.00	1020	1	0.0818	3	27.69
297	0	0.0595	1	36.00	659	1	0.0545	3	19.29	1021	2	0.0818	3	24.00
298	0	0.0595	1	30.00	660	2	0.0545	3	21.60	1022	2	0.0818	3	27.69
299	4	0.0595	1	22.50	661	4	0.0545	3	22.50	1023	1	0.0818	3	21.18

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
300	4	0.0595	1	30.00	662	0	0.0545	3	27.00	1024	0	0.0818	3	21.18
301	2	0.0595	1	30.00	663	1	0.0545	3	25.71	1025	0	0.0818	3	22.50
302	3	0.0595	1	36.00	664	4	0.0545	3	25.71	1026	2	0.0818	3	36.00
303	5	0.0595	1	20.00	665	4	0.0545	3	22.50	1027	0	0.0818	3	40.00
304	0	0.0595	1	25.71	666	1	0.0545	3	24.55	1028	1	0.0818	3	36.00
305	0	0.0595	1	45.00	667	0	0.0545	3	20.77	1029	1	0.0818	3	32.73
306	2	0.0595	1	45.00	668	0	0.0545	3	20.77	1030	0	0.0818	3	25.71
307	2	0.0595	1	45.00	669	2	0.0545	3	21.60	1031	1	0.0818	3	27.69
308	0	0.0595	1	25.71	670	0	0.0545	3	21.60	1032	0	0.0818	3	40.00
309	0	0.0595	1	36.00	671	0	0.0545	3	20.77	1033	0	0.0818	3	30.00
310	1	0.0595	1	45.00	672	4	0.0545	3	20.00	1034	2	0.0818	3	36.00
311	4	0.0595	1	36.00	673	5	0.0545	3	21.60	1035	4	0.0818	3	36.00
312	5	0.0595	1	45.00	674	5	0.0545	3	25.71	1036	2	0.0818	3	36.00
313	4	0.0595	1	30.00	675	5	0.0545	3	20.77	1037	2	0.0818	3	22.50
314	0	0.0595	1	36.00	676	0	0.0545	3	25.71	1038	0	0.0818	3	25.71
315	2	0.0595	1	20.00	677	1	0.0545	3	24.55	1039	2	0.0818	3	22.50
316	2	0.0595	1	18.00	678	0	0.0545	3	25.71	1040	0	0.0818	3	30.00
317	2	0.0595	1	18.00	679	2	0.0545	3	21.60	1041	0	0.0818	3	30.00
318	1	0.0595	1	20.00	680	0	0.0545	3	22.50	1042	1	0.0818	3	25.71
319	2	0.0595	1	22.50	681	0	0.0545	3	17.42	1043	4	0.0818	3	32.73

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
320	2	0.0595	1	20.00	682	2	0.0545	3	24.55	1044	2	0.0818	3	36.00
321	2	0.0595	1	36.00	683	3	0.0545	3	20.00	1045	3	0.0818	3	24.00
322	1	0.0595	1	25.71	684	1	0.0545	3	20.00	1046	0	0.0818	3	30.00
323	0	0.0595	1	25.71	685	1	0.0545	3	23.48	1047	1	0.0818	3	30.00
324	0	0.0595	1	30.00	686	5	0.0545	3	20.77	1048	2	0.0818	3	40.00
325	2	0.0595	1	30.00	687	5	0.0545	3	20.77	1049	0	0.0818	3	27.69
326	2	0.0595	1	36.00	688	1	0.0545	3	20.00	1050	1	0.0818	3	27.69
327	0	0.0595	1	36.00	689	5	0.0545	3	20.00	1051	0	0.0818	3	30.00
328	2	0.0595	1	25.71	690	2	0.0545	3	21.60	1052	1	0.0818	3	25.71
329	3	0.0595	1	22.50	691	4	0.0545	3	20.77	1053	4	0.0818	3	22.50
330	0	0.0595	1	22.50	692	2	0.0545	3	22.50	1054	0	0.0818	3	24.00
331	2	0.0595	1	20.00	693	2	0.0545	3	23.48	1055	2	0.0818	3	21.18
332	0	0.0595	1	22.50	694	4	0.0545	3	19.29	1056	1	0.0818	3	20.00
333	2	0.0595	1	20.00	695	4	0.0545	3	20.00	1057	0	0.0818	3	25.71
334	0	0.0292	1	45.00	696	0	0.0545	3	20.77	1058	1	0.0818	3	22.50
335	0	0.0292	1	45.00	697	1	0.0545	3	20.00	1059	0	0.0818	3	25.71
336	5	0.0292	1	21.18	698	1	0.0545	3	20.00	1060	1	0.0818	3	32.73
337	5	0.0292	1	20.00	699	0	0.0545	3	19.29	1061	2	0.0818	3	32.73
338	2	0.0292	1	36.00	700	1	0.0545	3	21.60	1062	2	0.0818	3	40.00
339	0	0.0292	1	30.00	701	0	0.0545	3	21.60	1063	4	0.0818	3	27.69

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
340	5	0.0292	1	22.50	702	0	0.0545	3	22.50	1064	2	0.0818	3	27.69
341	0	0.0292	1	36.00	703	2	0.0545	3	24.55	1065	1	0.0818	3	25.71
342	1	0.0292	1	36.00	704	1	0.0545	3	27.00	1066	2	0.0818	3	30.00
343	2	0.0292	1	45.00	705	5	0.0545	3	23.48	1067	0	0.0818	3	30.00
344	0	0.0292	1	45.00	706	1	0.0545	3	27.00	1068	1	0.0818	3	30.00
345	0	0.0292	1	40.00	707	0	0.0545	3	24.55	1069	1	0.0818	3	30.00
346	5	0.0292	1	36.00	708	1	0.0545	3	24.55	1070	3	0.0818	3	24.00
347	4	0.0292	1	20.00	709	0	0.0545	3	24.55	1071	5	0.0818	3	20.00
348	2	0.0292	1	40.00	710	4	0.0545	3	20.00	1072	1	0.0818	3	20.00
349	5	0.0292	1	32.73	711	0	0.0545	3	20.77	1073	5	0.0818	3	24.00
350	0	0.0292	1	45.00	712	1	0.0545	3	23.48	1074	1	0.0818	3	30.00
351	2	0.0292	1	30.00	713	1	0.0545	3	23.48	1075	2	0.0818	3	30.00
352	5	0.0292	1	20.00	714	0	0.0545	3	19.29	1076	5	0.0818	3	20.00
353	5	0.0292	1	20.00	715	2	0.0545	3	22.50	1077	5	0.0818	3	27.69
354	5	0.0292	1	40.00	716	3	0.0545	3	23.48	1078	1	0.0818	3	20.00
355	2	0.0292	1	40.00	717	1	0.0545	3	25.71	1079	3	0.0818	3	24.00
356	4	0.0292	1	40.00	718	5	0.0545	3	20.77	1080	4	0.0818	3	22.50
357	2	0.0292	1	45.00	719	2	0.0545	3	22.50	1081	5	0.0818	3	20.00
358	0	0.0292	1	36.00	720	4	0.0545	3	21.60	1082	5	0.0818	3	20.00
359	3	0.0292	1	36.00	721	1	0.0545	3	22.50	1083	3	0.0818	3	22.50

Passenger Car Equivalence Under Several Upgrade Road Conditions | 2023

No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed	No	Vehicle type	Road grade	number of lanes	Vehicle Speed
360	2	0.0292	1	36.00	722	0	0.0545	3	21.60	1084	1	0.0818	3	30.00
361	2	0.0292	1	32.73	723	5	0.0545	3	22.50	1085	4	0.0818	3	25.71
362	4	0.0292	1	45.00	724	1	0.0545	3	28.42	1086	0	0.0818	3	32.73

APPENDIX D – NUMBER OF HIDDEN LAYERS FOR ANN

Training data: 70 %
 Validation data: 15 %
 Test data: 15 %
 Layer size: 5

Training Results
 Training finished: Met validation criterion ✓

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	72	1000
Elapsed Time	-	00:00:00	-
Performance	141	32.9	0
Gradient	343	0.264	1e-07
Mu	0.001	0.1	1e+10
Validation Checks	0	6	6

Model Summary
 Train a neural network to map predictors to continuous responses.
Data
 Predictors: Inputdata - [3x1086 double]
 Responses: OutputFN - [1x1086 double]
 Inputdata: double array of 1086 observations with 3 features.
 OutputFN: double array of 1086 observations with 1 features.
Algorithm
 Data division: Random
 Training algorithm: Levenberg-Marquardt
 Performance: Mean squared error
Training Results
 Training start time: 21-Nov-2023 15:05:18
 Layer size: 5

	Observations	MSE	R
Training	760	32.9380	0.7288
Validation	163	31.9468	0.7398
Test	163	39.1379	0.6716

5 Number of hidden layers

Training data: 70 %
 Validation data: 15 %
 Test data: 15 %
 Layer size: 10

Training Results
 Training finished: Met validation criterion ✓

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	16	1000
Elapsed Time	-	00:00:00	-
Performance	413	32.3	0
Gradient	811	0.586	1e-07
Mu	0.001	0.1	1e+10
Validation Checks	0	6	6

Model Summary
 Train a neural network to map predictors to continuous responses.
Data
 Predictors: Inputdata - [3x1086 double]
 Responses: OutputFN - [1x1086 double]
 Inputdata: double array of 1086 observations with 3 features.
 OutputFN: double array of 1086 observations with 1 features.
Algorithm
 Data division: Random
 Training algorithm: Levenberg-Marquardt
 Performance: Mean squared error
Training Results
 Training start time: 21-Nov-2023 15:06:22
 Layer size: 10

	Observations	MSE	R
Training	760	33.1774	0.7225
Validation	163	38.7867	0.7082
Test	163	37.2385	0.6749

10 Number of hidden layers

Training data: 70 %
 Validation data: 15 %
 Test data: 15 %
 Layer size: 15

Training Results
 Training finished: Met validation criterion ✓

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	11	1000
Elapsed Time	-	00:00:00	-
Performance	483	34.5	0
Gradient	1.14e+03	3.25	1e-07
Mu	0.001	0.1	1e+10
Validation Checks	0	6	6

Model Summary
 Train a neural network to map predictors to continuous responses.
Data
 Predictors: Inputdata - [3x1086 double]
 Responses: OutputFN - [1x1086 double]
 Inputdata: double array of 1086 observations with 3 features.
 OutputFN: double array of 1086 observations with 1 features.
Algorithm
 Data division: Random
 Training algorithm: Levenberg-Marquardt
 Performance: Mean squared error
Training Results
 Training start time: 21-Nov-2023 15:07:14
 Layer size: 15

	Observations	MSE	R
Training	760	36.4867	0.6825
Validation	163	30.9836	0.7104
Test	163	38.4674	0.7560

15 Number of hidden layers

Training data: 70 %
 Validation data: 15 %
 Test data: 15 %
 Layer size: 20

Training Results
 Training finished: Met validation criterion ✓

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	45	1000
Elapsed Time	-	00:00:00	-
Performance	546	32.2	0
Gradient	887	2.15	1e-07
Mu	0.001	0.01	1e+10
Validation Checks	0	6	6

Model Summary
 Train a neural network to map predictors to continuous responses.
Data
 Predictors: Inputdata - [3x1086 double]
 Responses: OutputFN - [1x1086 double]
 Inputdata: double array of 1086 observations with 3 features.
 OutputFN: double array of 1086 observations with 1 features.
Algorithm
 Data division: Random
 Training algorithm: Levenberg-Marquardt
 Performance: Mean squared error
Training Results
 Training start time: 21-Nov-2023 15:07:45
 Layer size: 20

	Observations	MSE	R
Training	760	33.1303	0.7168
Validation	163	32.8072	0.7406
Test	163	37.4027	0.7246

20 Number of hidden layers

NEURAL NETWORK FITTING

Import Training data: 70 % Validation data: 15 Layer size: 25 Test data: 15

Train Stop Training State Performance Error Histogram Regression Fit Test Test Plots Export Plot to Figure Generate Code Export Model

DATA SPLIT BUILD TRAIN PLOTS TEST EXPORT

Network Training Model Summary

Training Results

Training finished: Met validation criterion ✓

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	60	1000
Elapsed Time	-	00:00:01	-
Performance	1.38e+03	27.9	0
Gradient	1.84e+03	0.529	1e-07
Mu	0.001	0.01	1e+10
Validation Checks	0	6	6

Model Summary

Train a neural network to map predictors to continuous responses.

Data
 Predictors: Inputdata - [3x1086 double]
 Responses: OutputFN - [1x1086 double]
 Inputdata: double array of 1086 observations with 3 features.
 OutputFN: double array of 1086 observations with 1 features.

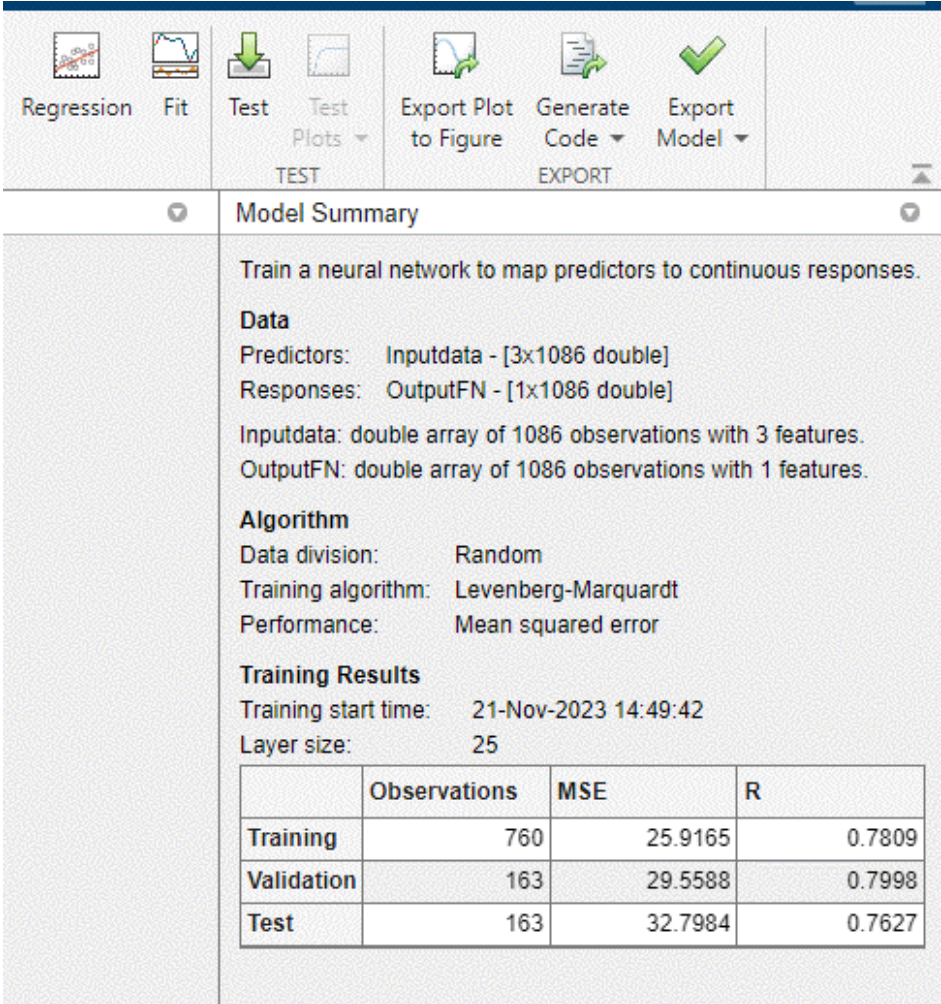
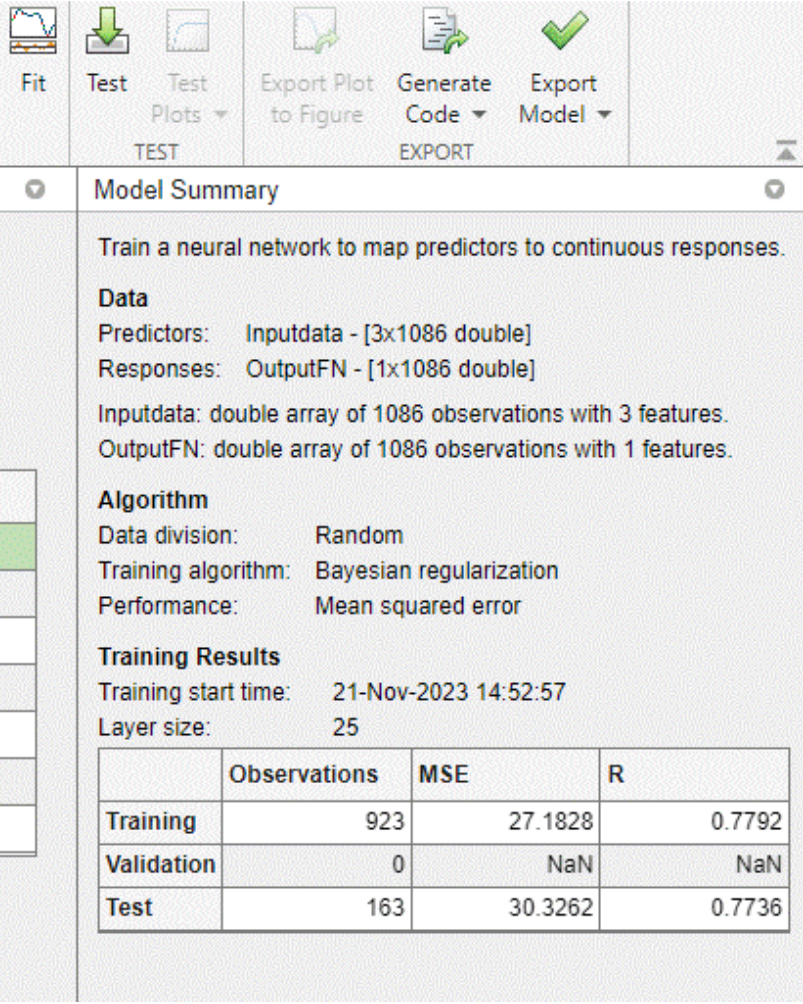
Algorithm
 Data division: Random
 Training algorithm: Levenberg-Marquardt
 Performance: Mean squared error

Training Results
 Training start time: 21-Nov-2023 15:08:37
 Layer size: 25

	Observations	MSE	R
Training	760	27.9272	0.7807
Validation	163	28.8645	0.7599
Test	163	25.4063	0.7857

25 Number of hidden layers

APPENDIX E – TRAINING ALGORITHM FOR ANN

 <p>Model Summary</p> <p>Train a neural network to map predictors to continuous responses.</p> <p>Data Predictors: Inputdata - [3x1086 double] Responses: OutputFN - [1x1086 double] Inputdata: double array of 1086 observations with 3 features. OutputFN: double array of 1086 observations with 1 features.</p> <p>Algorithm Data division: Random Training algorithm: Levenberg-Marquardt Performance: Mean squared error</p> <p>Training Results Training start time: 21-Nov-2023 14:49:42 Layer size: 25</p> <table border="1"> <thead> <tr> <th></th> <th>Observations</th> <th>MSE</th> <th>R</th> </tr> </thead> <tbody> <tr> <td>Training</td> <td>760</td> <td>25.9165</td> <td>0.7809</td> </tr> <tr> <td>Validation</td> <td>163</td> <td>29.5588</td> <td>0.7998</td> </tr> <tr> <td>Test</td> <td>163</td> <td>32.7984</td> <td>0.7627</td> </tr> </tbody> </table>		Observations	MSE	R	Training	760	25.9165	0.7809	Validation	163	29.5588	0.7998	Test	163	32.7984	0.7627	 <p>Model Summary</p> <p>Train a neural network to map predictors to continuous responses.</p> <p>Data Predictors: Inputdata - [3x1086 double] Responses: OutputFN - [1x1086 double] Inputdata: double array of 1086 observations with 3 features. OutputFN: double array of 1086 observations with 1 features.</p> <p>Algorithm Data division: Random Training algorithm: Bayesian regularization Performance: Mean squared error</p> <p>Training Results Training start time: 21-Nov-2023 14:52:57 Layer size: 25</p> <table border="1"> <thead> <tr> <th></th> <th>Observations</th> <th>MSE</th> <th>R</th> </tr> </thead> <tbody> <tr> <td>Training</td> <td>923</td> <td>27.1828</td> <td>0.7792</td> </tr> <tr> <td>Validation</td> <td>0</td> <td>NaN</td> <td>NaN</td> </tr> <tr> <td>Test</td> <td>163</td> <td>30.3262</td> <td>0.7736</td> </tr> </tbody> </table>		Observations	MSE	R	Training	923	27.1828	0.7792	Validation	0	NaN	NaN	Test	163	30.3262	0.7736
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Model Summary

Train a neural network to map predictors to continuous responses.

Data
 Predictors: Inputdata - [3x1086 double]
 Responses: OutputFN - [1x1086 double]
 Inputdata: double array of 1086 observations with 3 features.
 OutputFN: double array of 1086 observations with 1 features.

Algorithm
 Data division: Random
 Training algorithm: Scaled conjugate gradient
 Performance: Mean squared error

Training Results
 Training start time: 21-Nov-2023 14:55:17
 Layer size: 25

	Observations	MSE	R
Training	760	39.4176	0.6786
Validation	163	33.0627	0.6515
Test	163	36.8111	0.6856

Scaled Conjugate Gradient Training Algorithm

APPENDIX F – CALCULATION OF MODEL ACCURACY FOR ANN

No	Z'i	Zi	(Z'i) ²	Z'i-Zi	(Z'i-Zi) ²	[Z'i-Zi]/ Z'i	No	Z'i	Zi	(Z'i) ²	Z'i-Zi	(Z'i-Zi) ²	[Z'i-Zi]/ Z'i
1	24.00	25.69	576.00	-1.69	2.84	0.08	23.00	36.00	30.56	1296.00	5.44	44.24	0.16
2	27.69	27.10	766.86	0.59	0.35	0.05	24.00	20.00	29.75	400.00	-9.75	133.42	0.49
3	27.69	29.75	766.86	-2.06	4.25	0.07	25.00	32.73	30.56	1071.07	2.17	0.33	0.08
4	27.69	29.75	766.86	-2.06	4.25	0.07	26.00	32.73	25.12	1071.07	7.61	37.36	0.17
5	25.71	30.56	661.22	-4.85	23.47	0.17	27.00	32.73	29.75	1071.07	2.97	1.38	0.09
6	24.00	30.56	576.00	-6.56	43.02	0.26	28.00	36.00	30.56	1296.00	5.44	14.83	0.16
7	24.00	25.12	576.00	-1.12	1.25	0.14	29.00	30.00	29.75	900.00	0.25	2.41	0.01
8	22.50	30.56	506.25	-8.06	64.95	0.34	30.00	30.00	30.56	900.00	-0.56	4.62	0.01
9	25.71	30.56	661.22	-4.85	23.47	0.17	31.00	32.73	29.75	1071.07	2.97	1.38	0.09
10	25.71	29.75	661.22	-4.04	16.31	0.16	32.00	32.73	29.75	1071.07	2.97	1.38	0.09
11	32.73	27.10	1071.07	5.62	31.64	0.20	33.00	36.00	30.56	1296.00	5.44	34.24	0.16
12	18.95	29.75	359.00	-10.81	116.77	0.57	34.00	36.00	29.75	1296.00	6.25	19.79	0.17
13	25.71	29.75	661.22	-4.04	16.31	0.16	35.00	36.00	29.75	1296.00	6.25	29.69	0.17
14	32.73	30.56	1071.07	2.17	4.70	0.08	36.00	36.00	29.75	1296.00	6.25	19.79	0.17
15	18.95	25.69	359.10	-6.74	45.37	0.37	37.00	36.00	30.63	1296.00	5.37	14.95	0.16
16	36.00	30.63	1296.00	5.37	28.87	0.16	38.00	36.00	29.75	1296.00	6.25	19.79	0.17
17	30.00	29.75	900.00	0.25	0.06	0.01	39.00	36.00	30.56	1296.00	5.44	14.83	0.16
18	30.00	29.75	900.00	0.25	0.06	0.01	40.00	36.00	30.56	1296.00	5.44	8.13	0.16
19	36.00	30.63	1296.00	5.37	28.87	0.16	41.00	22.50	29.75	506.25	-7.25	81.92	0.32

No	Z'i	Zi	(Z'i) ²	Z'i-Zi	(Z'i-Zi) ²	[Z'i-Zi]/ Z'i	No	Z'i	Zi	(Z'i) ²	Z'i-Zi	(Z'i-Zi) ²	[Z'i-Zi]/ Z'i
20	32.73	30.56	1071.07	2.17	4.70	0.08	42.00	24.00	30.56	576.00	-6.56	66.40	0.26
21	36.00	30.56	1296.00	5.44	29.60	0.16	43.00	30.00	30.56	900.00	-0.56	4.62	0.01
22	40.00	29.75	1600.00	10.25	104.99	0.26	44.00	32.73	30.56	1071.07	2.17	0.34	0.08
Total										41967.76		1,226.07	7.05
										RMSE	5.25		
										MAPE	15.74%		
										RRMSE	16.87%		

APPENDIX G – 85%ILE SPEED UNDER EACH GRADE

10.28% Road Grade			5.95% Road Grade			6.36% Road Grade		
Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi
Passenger car	33.88	1.00	Passenger car	37.41	1.00	Passenger car	21.86	1.00
Pickup	34.88	0.97	Pickup	40.25	0.93	Pickup	21.84	1.00
minibus	37.00	0.92	minibus	38.38	0.97	minibus	21.00	1.04
bus	27.46	1.23	bus	35.25	1.06	bus	21.38	1.02
medium truck	23.00	1.47	medium truck	35.75	1.05	medium truck	21.25	1.03
heavy truck	33.75	1.00	heavy truck	41.00	0.91	heavy truck	19.50	1.12
7.68% Road Grade			2.95% Road Grade			5.45% Road Grade		
Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi
Passenger car	31.60	1.00	Passenger car	41.38	1.00	Passenger car	22.56	1.00
Pickup	27.45	1.15	Pickup	41.00	1.01	Pickup	24.18	0.93
minibus	35.10	0.90	minibus	40.10	1.03	minibus	22.25	1.01
bus	27.45	1.15	bus	35.25	1.17	bus	20.25	1.11
medium truck	23.00	1.37	medium truck	40.50	1.02	medium truck	22.00	1.03
heavy truck	33.75	0.94	heavy truck	35.00	1.18	heavy truck	22.35	1.01

7.34% Road Grade			4.04% Road Grade			3.64% Road Grade		
Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi
Passenger car	31.80	1.00	Passenger car	40.78	1.00	Passenger car	24.21	1.00
Pickup	26.75	1.19	Pickup	41.25	0.99	Pickup	24.59	0.98
minibus	33.63	0.95	minibus	41.15	0.99	minibus	24.13	1.00
bus	26.00	1.22	bus	36.38	1.12	bus	19.13	1.27
medium truck	31.75	1.00	medium truck	38.75	1.05	medium truck	23.75	1.02
heavy truck	36.00	0.88	heavy truck	35.75	1.14	heavy truck	22.32	1.08
5.88% Road Grade			7.45% Road Grade					
Vehicle type	85%ile Vehicle speed	Vc/Vi	Vehicle type	85%ile Vehicle speed	Vc/Vi			
Passenger car	21.67	1.00	Passenger car	36.14	1.00			
Pickup	21.58	1.00	Pickup	38.75	0.93			
minibus	21.70	0.99	minibus	40.25	0.90			
bus	20.25	1.07	bus	35.25	1.03			
medium truck	21.75	0.99	medium truck	35.00	1.03			
heavy truck	21.75	0.99	heavy truck	27.25	1.33			

157	2	0.0734	1	30.00	519	3	0.0745	1	32.73	881	5
158	0	0.0734	Passenger Car Equivalent Under Severe Upgrade Road Conditions	30.00	519	3	0.0745	1	30.00	882	4
159	2	0.0734	1	36.00	521	3	0.0745	1	40.00	883	1

APPENDIX H – TRAINED MATLAB CODE TO PREDICT VEHICLE SPEED

```

% Solve an Input-Output Fitting problem with a Neural Network
% Script generated by Neural Fitting app
% Created 24-Sep-2023 03:34:15
% This script assumes these variables are defined:
%   Inputdata - input data.
%   Outputdata - target data.
x = Inputdata;
t = Outputdata;
% Choose a Training Function
% For a list of all training functions type: help nntrain
% 'trainlm' is usually fastest.
% 'trainbr' takes longer but may be better for challenging problems.
% 'trainscg' uses less memory. Suitable in low memory situations.
trainFcn = 'trainlm'; % Levenberg-Marquardt backpropagation.
% Create a Fitting Network
hiddenLayerSize = 25;
net = fitnet(hiddenLayerSize,trainFcn);
% Setup Division of Data for Training, Validation, Testing
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;
% Train the Network
[net,tr] = train(net,x,t);
% Test the Network
y = net(x);
e = gsubtract(t,y);

```

```
performance = perform(net,t,y)

% View the Network
view(net)

%loadoutsample data for vehicle speed
op='TrialinputData';

%to predict outcomebased on observation 45, foroutsample can replace x
%with new datafile name
a=net(op)

% Plots
% Uncomment these lines to enable various plots.

%figure, plotperform(tr)
%figure, plottrainstate(tr)
%figure, ploterrhist(e)
%figure, plotregression(t,y)

%figure, plotfit(net,x,t)
```