ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EVALUATION OF THE PERFORMANCE OF HIGH OCCUPANCY VEHICLE (HOV) LANE ON A MULTILANE ROUTE IN ADDIS ABABA CITY:

A CASE STUDY ON LAMBERET BUS TERMINAL – KARALO ROUTE.

By

Meseret Yeshitila G/mariam

A Thesis Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

In

Road and Transport Engineering

Advisor:

Alemayehu Ambo (PhD)

November 2017

Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

M.Sc. Thesis on

EVALUATION OF THE PERFORMANCE OF HIGH OCCUPANCY VEHICLE (HOV) LANE ON A MULTILANE ROUTE IN ADDIS ABABA CITY:

A CASE STUDY ON LAMBERET BUS TERMINAL – KARALO ROUTE.

By

Meseret Yeshitila G/mariam

Approved by board of examiners:

Alemayehu Ambo (PhD)	______________	________
Advisor	Signature	Date
Bikila Teklu (Phd)	______________	________
Internal Examiner	Signature	Date
Atakilti	______________	________
External Examiner	Signature	Date
______________	______________	________
Dean, School of Civil and Environmental Engineering	Signature	Date

UNDERTAKING

I certify that this research work titled "**EVALUATION OF THE PERFORMANCE OF HIGH OCCUPANCY VEHICLE LANE ON A MULTILANE ROUTE IN ADDIS ABABA: A CASE STUDY ON LAMBERET BUS TERMINAL – KARALO ROUTE**" is my own work. The work has not been presented elsewhere for assessment and award of any degree or diploma. Where material has been used from other sources it has been properly acknowledged.

Meseret Yeshitila	....	....
Name	Signature	Date

Table of Content

Acknowledgements

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, my utmost gratitude goes to my advisor Dr. Alemayehu Ambo, for his unreserved support, sincerity and encouragement in the completion of this research work. I am also very thankful to Transport Programs Management office; especially Engineer Abselom from Traffic Safety department for his unlimited support on VISSIM software and all the members of the department for their time and invaluable feedback.

I would like to acknowledge Addis Ababa City Road Authority (AACRA); especially Engineer Michael from Road Design department for corporation in giving necessary data and for his support which is very appreciated. I also would like to extend my acknowledgement to Ministry of Education (MOE) for the female scholarship opportunity and for their continuous support throughout my graduate study.

I would also like to thank to the administrator and waiters of Champion café & restaurant and shop holders of Yeka Subcity; Kotebe Electric power condominium for their kindness when I was video recording the traffic flow. My cousin Girum Kefelgne & my best Abrham Belete, I would like to appreciate your valuable help during video recording the traffic flow simultaneously on five weekdays at different locations.

Last but not least, I would like to thank my siblings; Tigist Yeshitila, Mirkat Yeshitila and Wogayehu Yeshitila and all my friends for their undeniable support throughout for which my mere expression of thanks likewise does not suffice.

ABSTRACT

Metropolitan areas have long had a history of experiencing vehicular traffic congestion particularly during peak hours for different reasons. One overlooked factor among such contributory reasons is the disorganized utilization of similar lanes by a mix of light automobiles with one or two passengers on one hand and high occupancy vehicles with well over four passengers on the other hand. High occupancy vehicles are usually public transportation motors that continuously make frequent stops to pick up and deliver passengers from/to multiple destinations along a certain corridor. Therefore, the blending of vehicles that make a non-stop through movement with such high occupancy vehicles naturally results in a poor lane utilization and reduced level of service.

Addis Ababa is no stranger to this phenomenon as over one fourth of vehicular traffic on most multilane highways comprises of high occupancy vehicles. The problem is magnified as traffic management schemes that are non-infrastructural in nature are hardly exercised. This research focused on quantifying to what extent level of service on multilane highways could be improved by dedicating a single lane to high occupancy vehicles. Accordingly, a specific route was carefully chosen as a case study and the currently existing level of service was determined. In order to investigate the possible room for improvement, straight through lanes both in the middle and curb side were assigned to high occupancy vehicles one after the other and the new level of service for each lane was determined with the aid of a simulating software.

Results indicated that dedicating outer through lanes to high occupancy vehicles on the chosen case study can result in better lane utilization and improved level of service from D to C as evident from the registered shorter travel time as well as increased average speed.

KEY WORDS: HOV lane, traffic management, traffic flow, performance evaluation, simulation.

List of Tables

List of Figures

List of Acronyms

AACRA: Addis Ababa City Road Authority

ACBSE: Anbessa City Bus Service Enterprise

AM: Amplitude Modulation

BRT: Bus Rapid Transport

CADD: Computer Aided Drafting Design

CHP: California Highway Patrol

CORSIM: Corridor Simulation

FHWA: Federal Highway Agency

FRESIM: Freeway Simulation

GB: Giga Bite

GP: General Purpose

GPS: Global Positioning System

GSM: Global System for Mobile communication

HCM: Highway Capacity Manual

HGV: Heavy Good Vehicles

Hr.: Hour

HOV: High Occupancy Vehicle

Km: Kilometer

ITS: Information Technology System

LBS: Location Based System

LED: Light Emitting Diodes

LOS: Level of Service

MMUTCD: Minnesota Manual on Uniform Traffic Control Devices

NETSIM: Network Simulation

NCHRP: National Cooperative Highway Research Program

PM: Phase Modulation

RFID: Radio Frequency Identification

TDM: Transport Demand Management

TSM: Transport System Management

UDOT: Utah Department of Transportation

UK: United Kingdom

US: United States

VISSIM: Visual Simulation

WSDOT: Wisconsin Department of Transportation

CHAPTER 1

INTRODUCTION

1.1 General

Transportation has always played a vital role in the development of any nation. As stated by Oyadiran & Aregbesola, (2008*)*, the primary function of transportation is to move passengers or goods from places of lesser values to places of higher values or utilities. In a developing country such as Ethiopia, the transportation infrastructure has undeniable contribution to the welfare of the public and private sectors. Similarly, the availability of vehicles is important in transporting passengers from their points of origin to destination.

According to the World Bank Report (2015), Addis Ababa is home to about 25% of the urban population in Ethiopia and is one of the fastest growing cities in Africa.

In Addis Ababa, there are 7,500 blue-white painted minibus taxis, 800 operational buses managed by the state-owned Anbessa City Bus Service Enterprise (ACBSE), 500 Higer midi buses, 25 privately owned Alliance Transport S.C. buses, supported by 4,000 white minibuses and 400 cross-country buses (Fortune, 2015: Vol 16). However, it has not so enhanced the intended mobilization of the nation's development. This necessitates a well-managed road transport to boost up the growth process through a variety of activities of the development endeavors.

High Occupancy Vehicle (HOV) lane method is a type of traffic management that focuses on restricted travel lanes on highways and major arterials that are reserved at peak travel times or prolonged periods for exclusive use by multi occupant vehicles, including carpools, vanpools and transit buses. (Urban Transportation Showcase Program, 2007).

Federal-Aid Highway Program Guidance on HOV lane, stated the primary purpose of an HOV lane which is to increase the total number of people moved through a congested corridor by offering two kinds of incentives. The incentives are a saving in travel time and a reliable and predictable travel time. HOV lanes are normally employed to increase average vehicle occupancy and persons traveling with the goal of reducing traffic congestion and air pollution. The normal minimum per vehicle occupancy level of HOV lane is 2 to 3 persons.

1.2 Motivation

In Ethiopia, traffic congestion has always been one area that researcher is most attracted to. There are number of reasons for traffic congestion among them insufficient traffic management technique is significant. The fact that not any researches in Ethiopia haven't been done regarding HOV lane traffic management technique has motivated the researcher to contribute whatever little it might be in her own capacity on performance evaluation of HOV lane method.

In lite of the aforementioned, the fundamental scope of this study is to evaluate the performance of HOV Lane method on selected route in Addis Ababa through literature reviews, practical observation; video recording of traffic flow and simulating HOV lane on VISual SIMulation (VISSIM) software which is a simulation program for modeling multimodal transport operations and belongs to the Vision Traffic Suite software.

1.3 Statement of the problem

In Addis Ababa traffic congestion become part of a day - to - day activities and passengers are facing serious mobility problems. Especially at peak hour, almost all of Addis Ababa's arterial roads are congested. Even if those vehicular traffic in Addis Ababa is mainly managed through traffic police officers, signal lights, traffic signs, roundabouts and the like, but still traffic congestion remains Addis Ababa's major problem.

Transport users spend their precious time on long traffic queues and at the same time, fuel emission of vehicles getting increased. In this regard, a study may be required to understand the causes of the problems and suggest possible solutions. The creation of a means for efficient movement of High Occupancy Vehicles (HOV) may be one possible solution. With this in mind, this research is focused on identifying the causes of traffic congestion and come up with possible solutions through simulating alternative traffic management using HOV lane method and ultimately to minimize Addis Ababa's peak hour traffic congestion.

1.4 Research Questions

The main questions that should be answered through this are:

- What are the factors that induce congestion on the selected Addis Ababa route?
- What should be done to address those factors?
- Does HOV lane reduce the peak hour travel time?

1.5 Objectives

1.5.1 General Objective

The main objective of this research is to evaluate the plausibility and performance of HOV Lane on Lamberet Bus Terminal - Karalo route in Addis Ababa.

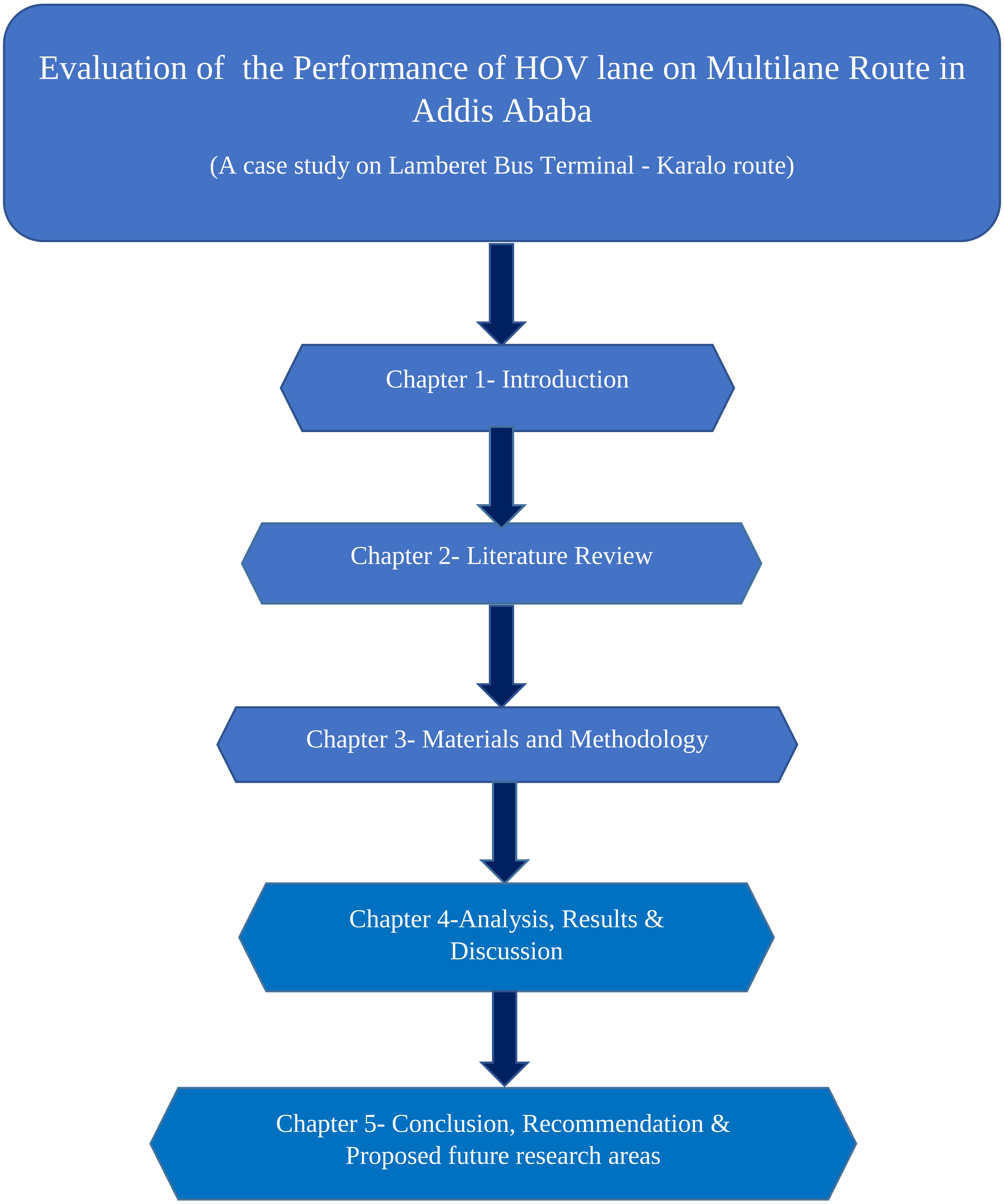
1.5.2 Specific Objectives

The specific objectives of this research are:

- To assess the current traffic management techniques on Lamberet Bus Terminal - Karalo route;
- To evaluate the performance of Lamberet Bus Terminal - Karalo route under the existing traffic management conditions and;
- To study the performance of Lamberet Bus Terminal – Karalo route by introducing HOV lane.

1.4. Organization of the Report

The following diagram illustrates the flow of the thesis report:



CHAPTER 2

LITERATURE REVIEW

2.1. Background

Currently, the Addis Ababa traffic management is basically limited only to traffic police officers, signal lights, traffic signs and roundabouts. However, there are different kinds of traffic management systems and mechanisms that are available globally and may be considered for implementation in Ethiopia in general and in Addis Ababa in particular. Therefore, this study has focused on contributing to alternatives in traffic management and lessen the challenges of the Addis Ababa's traffic management.

2.2. Summary of related literatures

In light of the Transport Policy of Addis Ababa, Addis Ababa is exhibiting high social, economic and structural changes, which generally qualifies it as a fast-growing city. In the case of transportation vehicles, more than seventy percent (70 %) of registered vehicles in the country are operating in Addis Ababa (Transport policy of Addis Ababa, 2011). Taking into account Addis Ababa‘s fast economic growth character and to enable the transportation sector to play its intended role, the Government has invested huge resources on road network expansion.

2.2.1. History of High Occupancy Vehicle (HOV) Lanes

As stated by Federal-Aid Highway Program Guidance on HOV Lanes, 2016, motorcycles, emergency vehicles including ambulances and identified vehicles of police or fire department, public transportation vehicles with or without passengers, privately owned buses that are designed to carry 15 or more passengers are eligible to use HOV lanes.

The development of HOV facilities was acquired since the early 1970s. Many of the initial HOV lanes were bus-only applications or allowed buses and vanpools. In an effort to maximize use, carpools or ridesharing became the dominant use group on most projects during the 1970s and 1980s. A 3+ occupancy level was initially used on many projects, but most current facilities use a two-person per vehicle (2+) carpool designation. (Federal-Aid Highway Program Guidance on High Occupancy Vehicle (HOV) Lanes, 2016). Figure 2.1 and 2.2 shows giving priority to high-occupancy vehicles. It works best when lots of people share one vehicle.

Figure 2.1. Giving priority to high-occupancy vehicles

Source: http://www.accessmagazine.org/articles/spring-1995/

Fig 2.2. Priority when lots of people share one vehicle

Source: http://www.accessmagazine.org/articles/spring-1995/

The introduction of HOV lane in different countries started since 1970. For instance, referring, "*High-occupancy Vehicle Lane – History*", on LiquiSearch website, HOV lanes in the U.S. progressed slowly during the 1970s and early 1980s. The progress became fast from the mid-1980s to the late 1990s. In California, the first permanent HOV facility was the bypass lane at the San Francisco-Oakland Bay Bridge toll plaza which was opened to the public in April 1970. It was one of the most efficient HOV facilities in North America and it is currently being converted to High occupancy toll lane operation to allow low-occupancy vehicles to bid for excess capacity on the lane in the metropolitan express lane projects.

Similarly, the website states that in Canada the first HOV facilities were opened in Greater Vancouver and Toronto in the early 1990s, followed shortly by Ottawa, Gatineau, Montreal and later in Calgary. As of 2010, there were around 150 km of highway HOV lanes in 11 locations in British Columbia, Ontario and Quebec, and over 130 km of arterial HOV lanes in 24 locations in Greater Vancouver, Calgary, Toronto, Ottawa and Gatineau. The average rush hour speed on the HOV lanes is 100 km/h compared to 60 km/h in general traffic lanes.

Because European cities have far better public transportation services and fewer high capacity multi-lane urban motorways than United States and Canada, there were few HOV lanes operation in 2012. The first HOV lane in Europe was opened in the Netherlands in October 1993 and operated until August 1994. The HOV facility was a 7-km barrier-separated HOV 3+ on the Amsterdam. But the facility did not attract enough users to overcome public criticism and was converted to a reversible lane open to the general traffic after the judge in a legal test case ruled that the Dutch traffic law lacked the concept of a car pool or ridesharing and thus that the principle of equality was violated. Next to Netherlands, in 1995, Spain was the next European country to introduce HOV lanes. This facility is Europe's oldest HOV facility which still gives service. In United Kingdom (UK), the first permanent HOV lanes opened in Leeds in 1998. The HOV lanes is 1.5 km long and operates as a HOV 2+ facility. After UK, in 1999, another HOV 3+ facility with 2.8 km opened in Linz, Austria. The first Sweden's HOV 3+ facility was opened in Stockholm in 2008 which is 8 km long. In addition, the first HOV lane in Norway was implemented in May 2001 as a HOV 3+ on Elgeseter Street, which was an undivided four-lane arterial road in Trondheim (http://www.liquisearch.com/high-occupancy_vehicle_lane/history).

2.2.2. High Occupancy Vehicle (HOV) Lane Facilities

According to NCHRP report 414 "HOV Systems Manual", there are three common types of HOV lanes. These are concurrent flow, contraflow, reversible flow and two directional flow HOV lanes. In addition, exclusive HOV lanes can be operated either two-way or reversible.

Concurrent flow HOV lanes are run in the same direction as the adjacent general-purpose lanes. Not physically separated from the general-purpose traffic lanes but paint striping is a common means used to delineate these lanes. These lanes are usually located on the inside lane. HOV facilities of this type are usually open to buses, vanpools and carpools.

Contraflow lane HOV lanes are usually operated during the peak periods only, and some operate only during the morning peak period and then revert to normal use in off-peak periods. The lane is separated from the general-purpose lanes by movable traffic barriers.

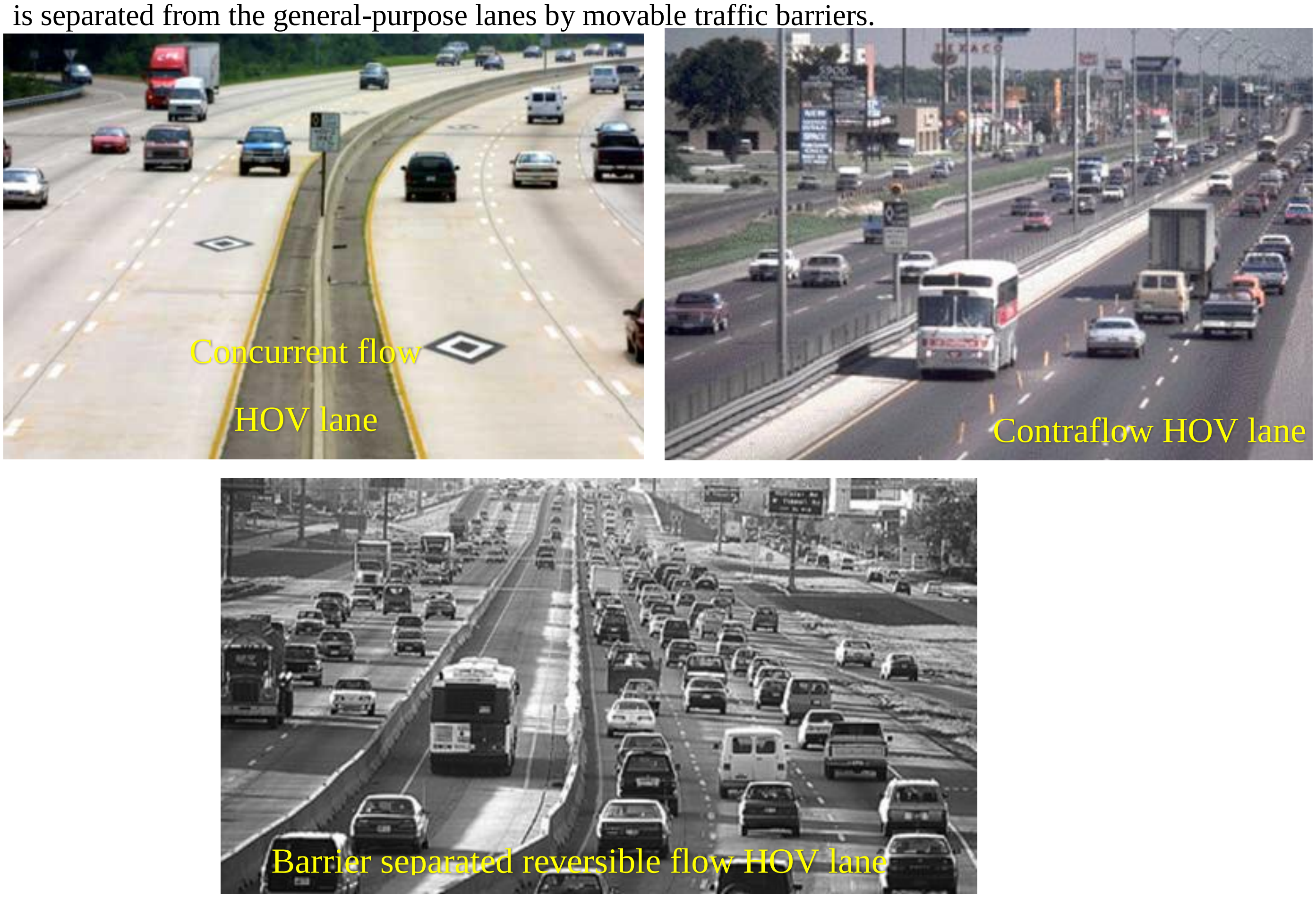


Figure 2.3: HOV lane facilities

Exclusive reversible HOV facilities usually operate one direction in the morning and the opposite direction in the afternoon. These facilities involve a lane or more lanes when there is an unequal traffic distribution and separated from the general-purpose lanes by concrete barriers; although a few facilities are separated by a wide painted buffer. These lanes are usually open to buses, vanpools and carpools. On the other hand, Two-way HOV facilities provide a lane or multiple lanes in either direction during the peak flow or for full-time use. These facilities commonly occur in areas where the traffic distribution is approximately equal in both directions, even during the morning and afternoon peaks. Like reversible-flow facilities, these lanes are often separated by barrier from the general lanes.

2.2.3. Effectiveness of High Occupancy Vehicle (HOV) lanes

HOV facilities have proven to be effective enhancements to the transportation system in many metropolitan areas.

As stated in the paper "Effectiveness of the HOV Lane in San Francisco Bay Area, 2007", from the constructed HOV lanes in California, some of them were underutilized. The study indicated that to avoid underutilization some ground rules would have been provided that allow toll-paying or hybrid vehicles access on HOV lane for increasing revenue and decreasing fuel emission. The paper analyzed four years' data during 2001-2005 from the San Francisco Bay area and addressed four main points. Those were; HOV lane excess capacity; Overall congestion; person throughput; and carpooling response to travel-time savings.

Since the study evaluated the effectiveness of the HOV lane on San Francisco bay area, it was performed on designated freeway segments by dedicating and restricting one lane (the leftmost, fast lane) for high-occupancy vehicles (2+ or 3+ persons) at peak hour during 5:00 a.m. - 9:00 a.m. and 3:00 p.m. - 7:00 p.m. on weekdays; for other days, the dedicated lane serves as a general-purpose lane. The evaluation considered comparison of traffic on the same lane with HOV lane and without.

The findings of the paper showed that the San Francisco Bay area required increase to its current 270 lane-miles by an additional 230 lane-miles at a cost of 3.7 billion dollars. In addition, HOV lanes exacerbate the congestion problem; that means, HOV lanes suffer a capacity drop of 400 vehicles/hour; which in general the

HOV lane increase congestion, don't significantly increase person throughput and also don't encourage people to share their ride; carpooling.

A research by Martin, Perrin & Wu and Lambert in collaboration with Utah Department of Transportation, 2004, targeted on evaluating the effectiveness of the I-15 HOV lane for purposes of policy-making decisions, including whether to implement HOV lanes on other freeways in the area and whether the minimum passenger level should be raised. The Utah Department of Transportation completed the reconstruction of I-15 road in Salt Lake City in May 2001. The reconstruction incorporates 16 miles (25.6 km) of HOV lane. This means that before the reconstruction, the I-15 lane has 3 GP lane on both north and east directions. The reconstruction increased the GP lane into 4 and added one HOV lane on both directions.

This literature considers a two-year research study that is before and after HOV lane implementation. In order to conduct the two-year study of I-15 HOV lane effectiveness, the Utah Department of Transportation (UDOT), in conjunction with the University of Utah and Mountain Plains Consortium, developed a federally supported Information Technology System (ITS) program.

Volume, speed, vehicle occupancy and violation rates were the parameters used to compare the HOV I-15 road and the reconstructed I-15 road. In addition, ongoing assessment and monitoring were additional keys to decide the acceptance and successful operation of HOV lane on other freeway lanes. In general, the aim of the research was to evaluate the impact of HOV lanes on I-15 and alternate routes; to measure the effectiveness of HOV lanes by comparing before-HOV-lane and after-HOV-lane statistics; to recommend changes to existing HOV operations policies or procedures; to review and recommend educational programs for improving HOV lane acceptance and compliance. Mainly the I-15 HOV lanes was constructed to increase the average number of persons per vehicle. Because of that, the HOV lanes of I-15 road are enforced 24 hours a day, seven days a week and reserve usage to vehicles with two or more passengers (carpools, vanpools and buses) and motorcycles. This enforcement created nationwide ambiguity whether HOV lane give service continuously or at peak hour.

The report by FHWA U.S Department of Transportation entitled "Review of HOV lane Performance and Policy Options in the United States", was organized into four tasks. The tasks were: preparation of detailed work plan; assembling available data and perform analysis of the performance of existing HOV Lanes in the United States; assembling available performance data and analyze the impacts of increasing occupancy requirements and final documentation. The study discussed the existing HOV facilities under categories of state, region and responsible agency category. A total of 345 HOV facilities were in the state inventory. In the region category were Minneapolis-St. Paul with 83 facilities followed by San Francisco Bay. The study described that the responsible agency for the HOV facility was the California Department of Transportation. The eligibility of HOV facilities are listed out in percent. Out of the 185 of the HOV facilities in the inventory, 54% carried purely 2+ passengers, and 14 of HOV facilities are carried 3+ passengers. In addition, there are two facilities that serve 3+ passengers during certain times of the day and 2+ on other times of the day. The paper evaluated the operating performance underutilization, peak hour violation rate, and peak hour travel time savings. The objectives of the paper were: improving air quality and encouraging carpooling in peak periods. In order to know the feedback of current HOV users, interview was conducted. (FHWA U.S Department of Transportation Report, 2008)

In California, the HOV lane facilities are promoted well. For 925 mile of HOV lane, the California state spent 2.3 billion dollars. The State has a plan to double the HOV lane facility by 2020. The expansion of the facility is supportive because the lane gives effective service by lowering travel time of the users. (Kwon & Varaiya, 2007)

Bourns College of Engineering prepared a report on Modeling the effectiveness of HOV lanes at improving air quality in 2006. The paper focused on a specific evaluation of HOV lanes that focuses on the air quality aspect together with a scientifically sound modeling toolset that provide reliable estimates of the air quality impacts of HOV lanes and develop a public domain modeling toolset consists of mesoscopic and microscopic modeling tool that can be used to provide reliable estimates of the air quality impacts of HOV lanes. The development of the modeling toolset consists of two major components.

The paper stated that the HOV lane air quality evaluation was conducted separately for HOV lanes in northern and southern California because of their different operational characteristics. The evaluation was performed by comparing the emissions from HOV lanes verses their mixed flow lane counterparts. For southern California, HOV lanes the emission comparison was made multiple times at utilized, neutral, well utilized and over utilized HOV lane operation scenarios. On the other hand, for northern California HOV lanes, the emissions comparison was made both when HOV lanes were actuated and when they were not actuated.

The data collection activities that were carried out on the study were traffic data, occupancy data, driving trajectory data and fleet composition estimation. Traffic flow and occupancy data of 23, 237 loops covering 2,812 out of 30,726 miles of interstate and state highways in California using Freeway Performance measurement system (PeMS) which is an interactive system that allows users to investigate various performance measures of the freeway system historically and in real time. Driving trajectory data was collected for both HOV and mixed traffic flow lanes using Global Positioning Satellite (GPS) and fleet composition estimation data collected from the California vehicle database. The collected data were analyzed using a microscopic emission modeling software which is comprehensive model emission (CMEM) software. CMEM is microscopic in the sense that it predicts second-by-second tailpipe emissions and fuel consumption based on different modal operations from in-use vehicle fleet. The study came up with two findings. The first main finding of the study was, under existing demand conditions due to the better flow of traffic in the HOV lanes, the HOV lanes on the freeway produce less pollutant emissions per lane as compared to the adjacent mixed flow lanes. The other finding was the HOV lanes are found to produce far less emissions per traveler than mixed flow lanes because of the average vehicle occupancy in the HOV lanes is approximately double of the average vehicle occupancy in the mixed flow lanes.

The study on Re-Allocation Road Space: Introducing HOV-Lane in the City of Trondheim focused on efficiently utilizing the existing road infrastructure with the introduction of HOV lane. In addition, the paper presents the provisional findings of the simulation study which was carried out to quantify the impacts of implementing HOV- lane on a major street at the city center of Trondheim as a means of reallocating road space. Previously in Norway, the driveway situation in south with four lanes, two in each direction with no bus lane but the situation inbounds that the right lane (nearest to the curb) has changed from an ordinary lane to a HOV-lane for use by buses and passenger vehicles with a minimum of two persons. Like the previous, the current situation doesn’t include bus lane.

The interesting aspect of the HOV lane of Trondheim city is that it appears in arterial street inside the city dealing with 5 signalized crossings of 8.5 km in length and also appears in a situation with relatively light congestion. For the simulation, the Corridor Simulation (CORSIM) software was used. The software was developed by the Federal Highway Agency (FHWA) in the USA. The findings from the simulation were quite a light congestion in the peak hour; introducing a HOV-lane will not reduce the total travel time for all travelers; the model shows that the speed is higher in the HOV-lane; and the HOV lane has the lowest traveling time. The SINTEF research institution at the technical university of Trondheim did the simulation. The main group of people who used the HOV lane are those currently going by bus, those who ride share, and those who will change mode. (Laegran, 2001)

As per Dixon and Alexander 2005, the HOV lane schemes which focused on existing HOV lane schemes, both in UK and overseas targeted on identifying areas where previous experience could be relevant to the design, operation and monitoring of the M1 HOV scheme, the following findings resulted;

- There is no standard design for the layout of HOV lanes or their operation;
- Signing for a HOV lane is usually placed at the start of the lane and at regular intervals along the scheme. However, there is no standard spacing for these signs;
- Signing gives details of minimum occupancy requirements and restrictions on times and vehicle types;
- Buses are always allowed to use the HOV lane, and Heavy Good Vehicles (HGV) are consistently banned from the HOV lane in the schemes reviewed;
- Integration with the surrounding network through the implementation of public transportation systems is considered key for the success of HOV schemes;
- Public awareness and understanding of HOV lanes and their purposes is key for their acceptance and continued legal use;
- There were no standard methods for evaluating HOV schemes; and
- The ongoing monitoring and assessment which include public opinion surveys is vital for continuing successful operation of HOV lanes.

The study of Safety performance of HOV facilities: Evaluation of HOV lane configurations in California mainly focused to understand the effect of different types of HOV access on safety. To this end, this study examines collisions that occurred in HOV and adjacent traveling lanes both at the statewide and corridor level. The paper examined collision data from HOV facilities with continuous and limited access.

On the analysis, relationship between collision rates in HOV facility and geometric attributes, including shoulder width, length of the access, and the proximity of the access to its neighboring ramps were considered.

The finding of the paper shows HOV facilities with limited access offer no safety advantages over those with a continuous access. Compared with continuous access HOV lanes, a higher percentage of collision was concentrated on limited access HOV lanes. Limited access HOV lanes also had higher collision state These findings provide enhanced understanding about the effects of geometric factors on the collision rates in HOV lanes

In addition, the paper stated the findings from investigating the relationship b/n collision rates in HOV lanes with respect to shoulder width, length of access, and the proximity of access to its neighboring ramps. HOV facilities with shoulder width greater than 8ft displayed significantly lower collision rates regardless of access type.

A paper entitled with High Occupancy Vehicle Lanes- An Overall Evaluation including Brisbane Case Studies, mainly focused on developing an effectiveness evaluation framework from literatures. The paper reviewed literatures regarding effectiveness, safety, public opinion, enforcement, environment and public and design guidance. To determine effectiveness measurement, the paper reviewed person moving efficiency, travel time savings, travel time reliability, transit efficiency, overall corridor efficiency and impact on general purpose (GP) lanes.

HOV facilities effectively evaluated, implemented and monitored can achieve their purpose of increasing the person moving capacity of a road corridor. They may not need to be long sections, some isolated queue jumps or road widenings may be sufficient to improve corridor efficiency rather than introducing long sections HOV lanes to avoid problem areas.

In the paper, evaluation framework compiled from literature reviews. The developed evaluation framework has objective, measure of effectiveness and target sections. The objective sections are Person moving efficiency, travel time savings, travel time reliability, transit efficiency, overall corridor efficiency, impact on GP lanes, public opinion, enforcement and safety.

The developed framework sections are interrelated. The objective section evaluated with measure of effectiveness section and the measure of effectiveness measured in the target section qualitatively and quantitatively.

Person moving efficiency measured as per average vehicle occupancy and HOV market share measure of effectiveness; travel time savings and travel time reliability measured from travel time difference and travel speed standard deviation aspects respectively; transit efficiency objective measured from vehicle productivity and bus reliability angle; overall corridor efficiency measured from per-lane efficiency of total corridor; impact on GP lanes measured from level of service and travel speed aspect; public opinion effectiveness measured from percentage support for HOV lane; enforcement measured from violation rate (% of ineligible vehicles using HOV lane); environmental objective measured from vehicle emissions, vehicle distance travelled, vehicle hours of travel and total fuel consumption angle and safety objective measured according to accident rate.

The paper mentioned that no universally accepted evaluation method was found for measuring the success or failure of HOV facilities. Therefore, the developed framework expected to be adopted by road authorities to use on HOV lanes now and in the future.

2.2.4. Benefits of High Occupancy Vehicle (HOV) Lanes

HOV lane provision increase the number of people, rather than the number of vehicles, being carried on a roadway due to encouraging greater use of buses, vanpools and carpools modes. The following picture illustrates way to accommodate more persons in fewer vehicles than automobiles with only one person.

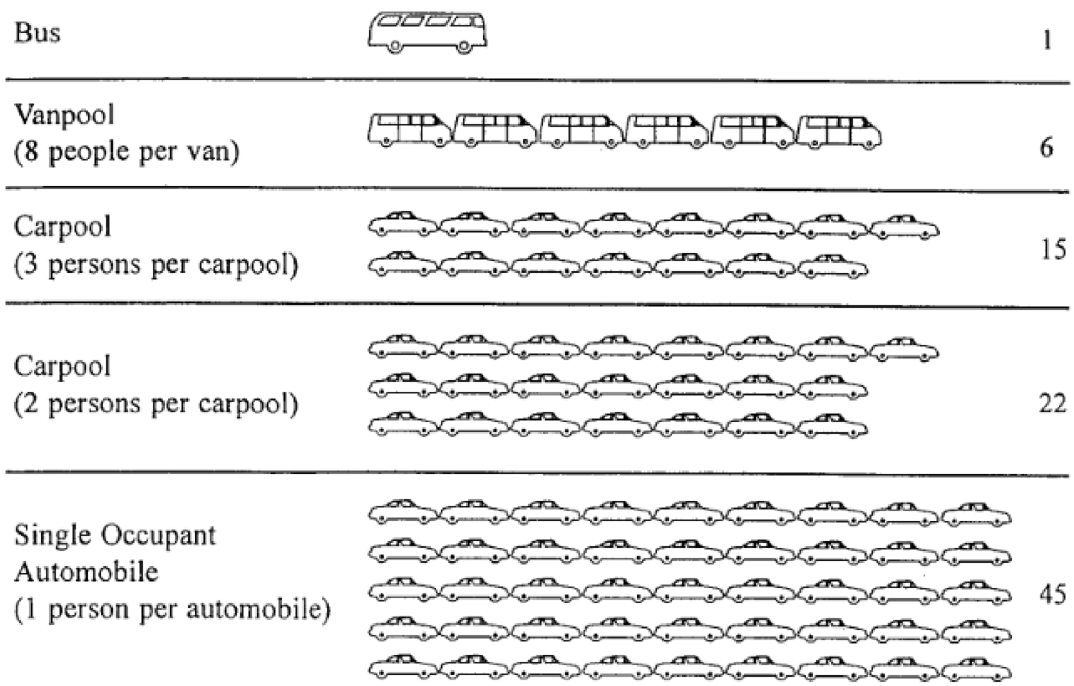


Figure 2.4: Number of vehicles needed to carry 45 people

Source: NCHRP Report 414 “HOV

The purpose of HOV facilities is not to force individuals to make changes against their will. Rather the objective to provide a cost-effective travel alternative that a significant volume of commuters will find attractive enough to change from driving alone to using a higher occupancy mode. (NCHRP Report 414, 1998)

Referring NCHRP report 414, Brndongaille and Access magazine website, HOV lane facilities have number of benefits. Some of the benefits are to increase the average number of persons per vehicle, preserve the person movement capacity of the roadway, enhance bus transit operations, limit carbon emission, make the commute faster, minimize fuel cost, provides a social outlet for people, reduces person delays, and reduces emissions.

The website also mentioned some disadvantages of HOV lane facilities. Those disadvantages are car owners can’t always leave work when you are ready to leave, because of ridesharing there are no quiet moments and also there may be costs, or fees associated with carpooling,

2.2.5. HOV lane enforcement evaluation

HOV lane enforcement evaluation by Cyulberg and Jacobson 1993, was on evaluation and enforcement techniques on a recently constructed portion of HOV lanes along I-405 in the Seattle, Washington area and a related public opinion survey concerning HOV lanes. The enforcement techniques were intensive and continuous, once a week saturation and stationary enforcement. The evaluation included public opinion with interviews and questionnaires. The evaluation was performed through interviews and questionnaires. In addition, the following were included; public support for HOV lanes, HOV lane enforcement related issues, and HOV lane enforcement to decrease violation.

Furthermore, the following were included: intensive enforcement period reduced from six months to three months; modify the Wisconsin Department of Transportation (WSDOT) design manual, provide turnaround and enforcement area on I-405, install bridge pier enforcement areas, consider barrier, increase HOV violation file, allow ticketing by mail, add additional enforcement personnel, develop a publicity program about the purpose and rules of HOV lanes.

The report on dot.ca.gov website states that, the goal of the California Highway Patrol (CHP) which is responsible for HOV lane enforcement was to keep HOV violation rate to less than 10%. to pay US$490. Once monitor counts detect violation rate above 10%, the action taken was to enforce the violators with a minimum HOV lane violation ticket of US$ 490 (http://www.dot.ca.gov/trafficops/tm/hov.html).

2.2.6. Methods to evaluate performance of HOV lanes

Literatures shows that when introducing HOV lanes, certain countries use microsimulation software analysis to evaluate the performance of HOV lanes.

Microsimulation analysis focuses on application of computer models to stochastically replicate traffic flow on the transportation facility. Some Inputs of Microsimulation traffic models are traffic volume, facility type and vehicle-driver characteristics. These input information use to move traffic using simple acceleration, gap acceptance, and lane change rules on a time step basis. As mentioned on Traffic Analysis handbook, common outputs of the microsimulation model are given per individual vehicle in form of text reports and visual animations. (Traffic Analysis Handbook, 2014)

Traffic Analysis Handbook, 2014, give emphasis on commonly used Corridor Simulation (CORSIM) and Visual Simulation (VISSIM) microsimulation software.

A paper entitled with Re-allocation road space: introducing HOV-Lane in City of Trondheim which presents the provisional findings, and the results of a simulation study that were carried out to quantify the impacts of implementing HOV-lane in a major street at the city center of Trondheim, as means of re-allocating road space. In the paper, for the simulation study CORSIM software has been used. The reason CORSIM was used because the software gives the opportunity for a detailed study of individual vehicles in movement. (Laegran, 2011)

According to Federal Highway Administration (2017), Corridor Simulation (CORSIM) software is comprehensive microscopic traffic simulation, applicable to surface streets, freeways, and integrated networks with a complete selection of control devices i.e. stop/yield sign and traffic signals. CORSIM has been applied by thousands of practitioners and researchers worldwide over the past 30 years.

CORSIM combines two of the most widely used traffic simulation models, NETwork SIMulation (NETSIM) for surface streets, and FREway SIMulation (FRESIM) for freeways. Table 2.1 below shows the key parameters of CORSIM software.

Indicators	CORSIM
Network parameters	Link data: length and grade; number of lanes and lane configuration; link curvature; bus stops; vehicle detectors; free flow speed.
Vehicle types	Seven vehicle types, including passenger cars, trucks and buses.
Vehicle characteristics	Distribution of acceleration and deceleration rates by speed and vehicle type; fleet distribution and passenger occupancy.
Traffic operations	Input traffic volumes and vehicle mix; turning movements at off ramps; OD patterns; Bus operations.
HOV operations	Predefined; Can select appropriate HOV lane entry and exit locations.
Ramp metering	Pre-defined; Can model all types of ramp metering, such as pre-timed, demand/capacity, etc.; one signal for all lanes (except HOV lane, automatic bypass)
Incident simulation	Predefined; Can select location, start time, duration, number of lanes, and nature of incident (i.e. lane blockage or rubber-necking).
Lane closure/work zones	Coded using the HOV feature.

Table 2.1: Key parameters of CORSIM software

Source: Comparative evaluation of simulation software for traffic operation, Dec 2002.

On the other hand, the study on Simulation analysis of Truck restricted and HOV lanes focused on analyzing the operational and safety experience of 83 Mile corridor in South Florida that has both HOV and truck lane restrictions implemented individually and in combination. The simulation analysis was done using VISSIM software. As stated on the paper, the reason VISSIM software was chosen because of its simplicity in modeling roadway segments, capability to visualize objects in three-dimensional space, ability to aggregate traffic performance measures per lane and for a certain vehicle types, and because it is less expensive. (Siuhi, 2006)

VISSIM is a stochastic, time-step and behavior-based microscopic simulation tool with driver-vehicle units as single entities. It is capable of modeling typical passenger vehicles and trucks on freeways and arterials and it can also analyze private and public transport operations under constraints such as lane configuration, vehicle composition and traffic signals; thus, making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness. Furthermore, it is capable of modeling truck and HOV lane in multilane roadways. (VISSIM 5.30-05 user manual, 2011). The following table shows the key Parameters of VISSIM software.

Indicators	VISSIM
Network parameters	Link data: length and grade; number of lanes and lane configuration; bus stops, vehicle detectors; free flow speed; Curved links can be drawn directly.
Vehicle types	Car, light truck, heavy truck, bus, articulated bus, Tram.
Vehicle characteristics	Distribution for maximum acceleration rates by speed and vehicle type.
Traffic operations	Input traffic volumes and vehicle mix; turning movements at off ramps; OD patterns; Bus operations.
HOV operations	Can be coded as "lane closures" with restricted vehicle types. HOV vehicles can enter/exit at any location.
Ramp metering	Coded as regular signal. Only pre-timed or actuated can be coded. Signal can be coded lane by lane. HOV bypass ok.
Incident simulation	Can simulate by creating a transit stop at incident location; Often difficult to coordinate start time and incident on multiple lanes.
Lane closure/work zones	Coded using the lane closure feature.

Table 2.2: Key parameters of the VISSIM software.

Source: Comparative evaluation of simulation software for traffic operation, 2002.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1. Introduction

In this chapter, the research materials and methodology elements are presented. Therefore, selection of the study area, study design, data collection methods, research data analysis methodology and research material are briefly described by sections as follows.

3.2. Selection of the study corridor

For the purpose of achieving the research objectives, an urban street route in Addis Ababa has been selected. This is mainly done in order to restrict one lane for High Occupancy Vehicles (HOV) from general purpose lanes on weekdays during peak hour.

3.2.1. Study Location

The study corridor is situated in Addis Ababa, Yeka Sub City so called "Wosen Grocery area". It starts at the western side of the Lamberet Bus Terminal and terminates at Karalo which covers an approximate distance of 5.40 km. The terrain is mostly rolling to hilly.

The study route has been found appropriate for this research because of the following reasons.

- It has morning hour traffic congestion;
- Due to the presence of Lamberet bus terminal, high occupancy vehicles which carry more than five passengers are using the route;
- The route has two straight through and one left lane on one side of the route which is important to dedicate one straight through lane for HOV lane and the other for general purpose lane;

Figure 3.1: Study location

3.2.2. Description of the study corridor

The route section; Lamberet Bus Terminal - Karalo route seems appropriate to achieve the objective of this research. This is because:

- Lamberet Bus Terminal – Karalo route has divided three lanes and separate left lane treatment.
- Based on AACRA Geometric Design Manual; section 4 - applications of design principles & standards; Lamberet Bus Terminal – Karalo route is classified under urban sub-arterial road. Similarly, based on Highway Capacity Manual (HCM) 2000, urban street classification, Lamberet Bus Terminal – Karalo route is classified under urban minor arterial route.
- The morning congested traffic flow starts from 7:30 – 9:30 AM but the peak hour traffic flow is from 8:00 – 9:00 AM, this is because there are two T- junctions which are at the gurdshola Mariam and Kotebe 02 area that provide morning traffic flow to this sub arterial road;
- The route has un signalized intersection. The morning traffic flow on the un signalized intersection is heavy and it is only managed through traffic police officers; and
- Small cars are using the route, but most of these cars carry two passengers including the driver.

Table below provides details on the study route characteristics

Description	Lamberet Bus Terminal – Karalo route
Design Category	Urban
Location	Yeka Sub city
Length	5.4 km
Road Classification	Minor Arterial
Lane width	3.6 m
Average number of through lanes	4 on both sides
Average number of right and left lanes	2 on both sides
Speed Limit	40 km/hr
Interchanges per KM	0
Average AADT	5815
Design speed	60 km/hr
ROW width	25 m

Table 3.1. Characteristics of the study route

Source: Addis Ababa Road Authority (AACRA)

3.3. Study Design

In this section, the overall design of the research is presented. Since observation is the starting point for identifying the problematic locations, the research design was initially started from observing the congested routes of Addis Ababa city.

3.4. Data Collection

In order to achieve the objective of this research, both primary and secondary data were collected.

3.4.1. Primary Data collection

Primary data were collected through video recorder in the morning on the subject route; Lamberet Bus Terminal – Karalo with following details:

- Primary Data type – Video recording of traffic flow data;

- Location/s and recording duration – Recording at two different locations for two hours per a day

3.4.1.1 Traffic flow recording using video cameras

The primary data of the research were collected using video camera. The traffic flow data recorded in morning peak hours from 7:30 am to 9:30 am on weekdays for five days from Monday to Friday. This was done because the morning traffic flow has lowered after 9:30 a.m. and due to that the congestion also reduced. In addition, the recorded traffic flow is used to identify the travel time, travel speed and level of service of peak hour traffic flow.

The type of traffic study is traffic volume count and the purpose of the traffic study is evaluation which is using recorded traffic data assess whether changes to the traffic system have resulted in the desired improvement in the traffic conditions.

The afternoon peak flow was not recorded because the afternoon traffic flow has been properly managed by current traffic management which doesn't require to re-allocating the GP lane to HOV lane. The recording was taken from at two locations with good views of the traffic flows. The locations are at champion café & Restaurant building and Yeka sub-city Kotebe Electric Power Condominium. Photo shoots of the traffic flows were made from two buildings and the side ramp walkway.

3.4.2. Secondary Data collection

The secondary data were acquired from the Addis Ababa City Roads Authority (AACRA). The acquired data were: route geometric values; functional classification; design speed and related data that were used for calculating the level of service (LOS) of the road and as parameters in utilizing the VISSIM Software.

3.5. Research Data analysis methodology

This section describes the overall data analysis methodology of the research. The collected data will be analyzed both on hand and using software simulation. Vehicle composition of the route, vehicle occupancy of the vehicles on the route, average travel time, average travel speed as well as level of service of the existing route will be determined from the hand analysis. On the other hand, the High Occupancy Vehicle lane performance evaluation will be evaluated from software simulation result. Vehicle composition of the route was determined by counting the recorded traffic flow in to five vehicle categories which are cars, city bus, medium bus, taxi and truck. Morning vehicle occupancy of the vehicles obtained from pilot study and from researcher observation while recording the traffic flow.

3.6. Research Material

PTV VISSIM 9 and Google earth software were used in doing this research. VISSIM software was used for evaluating the performance of HOV lanes. The inputs data for VISSIM were background image, number of lane, lane width, link length, vehicle composition, vehicle input (peak hour traffic flow) and assumed desired speed. The input data are analyzed using public transport line, public transport stop, vehicle travel time trajectory and simulation tools. The outputs from the VISSIM software are travel length, number of vehicles and travel time.

Google Earth software was used to acquire the route location. The route location image taken from this software was used as a background image input on VISSIM software.

Chapter 4

Analysis, Results and Discussions

4.1. Introduction

In this chapter, the research findings are discussed analytically, statistically, graphically, in tabular form and qualitatively. In this regard, the chapters are divided into three parts: Traffic flow analysis, Vehicular composition, and Lane selection.

4.2. Traffic flow analysis

In this section, the traffic flow of a 1km segment which is part of the Lamberet Bus Terminal – Karalo route has been analyzed with respect to travel time, travel speed and level of service.

4.2.1. Travel time

The most direct way of obtaining the travel time for several vehicles between two points in the highway system is by recording the time of entry and the time of exit for individual vehicles traversing the study section. (Adolf, 1990).

In this research, the travel time of the vehicles are taken from recorded traffic flow. For the purpose of calculating the travel time between entry and exit, the data recording was held at two points; at Champion building and at Yeka sub city Kotebe Electric power condominium.

From the five days counted traffic data, it was found that the both left and middle lanes have large traffic flow on Monday while the outer lane has large traffic flow on Tuesday. Vehicle travel time of those three lanes are registered, and the average travel time of those lanes were calculated. The following tables summarizes the registered travel time of different vehicles on left lane, middle lane and outer lane and their average travel times.

Average travel time by vehicle type			
Lane	Vehicle type	Travel length (Km)	Average Travel Time (Hr.)
Left	Small Car	1.0000	0.0727
	High Occupancy Vehicles (HOVs)	1.0000	0.0930
Middle	Small Car	1.0000	0.0366
	High Occupancy Vehicles (HOVs)	1.0000	0.0468
Outer	Small Car	1.0000	0.0437
	High Occupancy Vehicles (HOVs)	1.0000	0.0648

Table 4.1: Average travel time by vehicle type

Average travel time by lane		
Lane	Travel length (Km)	Average Travel Time (Hr.)
Left	1.0000	0.0790
Middle	1.0000	0.0374
Outer	1.0000	0.0449

Table 4.2: Average travel time by lane

4.2.2. Travel speed

Speed is defined as a fundamental measurement of the traffic performance on the highway system Most analytical and simulation models of traffic predict speed as the measure of performance given the design, demand and control on the highway system. It is also used as an indication of level of service.

In this research, average speed is used to determine the level of service of the segment. As stated in Highway Capacity Manual (HCM), 2000; for segment section, urban street level of service (LOS) is based on average through vehicle travel speed and the average speed is computed as the length of segment divided by the average travel time. The travel time is the time taken to traverse the street segment. Therefore, Average speed is calculated as:

$$\text{Average speed} = \frac{\text{Segment Length}}{\text{Average travel time}}$$

The following tables illustrate average travel speed by vehicle type and average travel speed by lane respectively.

Average travel Speed by vehicle type					
Lane	Vehicle type	Number of vehicles	Travel length (Km)	Average Travel Time (Hr.)	Average Travel Speed (Km/hr.)
Left	Small Car	113	1.0000	0.0727	13.75
	High Occupancy Vehicle	18	1.0000	0.0930	10.75
Middle	Small Car	99	1.0000	0.0366	27.32
	High Occupancy Vehicle	36	1.0000	0.0468	21.36
Outer	Small Car	59	1.0000	0.0437	22.88
	High Occupancy Vehicle	43	1.0000	0.0648	15.43

Table 4.3 : Average travel speed by vehicle type

Average travel speed by lane			
Lane	Travel length (Km)	Average Travel Time (Hr.)	Average Travel Speed (Km/hr.)
Left	1.0000	0.0790	12.82
Middle	1.0000	0.0417	24.00
Outer	1.0000	0.0542	18.45

Table 4.4: Average travel speed by lane

4.2.3. Level of service (LOS)

As stated by Rogers, 2003; LOS describes in a qualitative way the operational conditions for traffic from the viewpoint of the road user. On the text book, LOS referred as a gauge of congestion level on a highway in terms of variables such as travel time and traffic speed.

The route selection of this research which is Lamberet Bus Terminal – Karalo is a multilane route; but, since it is two-way with six lanes, HCM, 2000; categorized it under Urban street section.

Therefore, urban street level of service criteria is based on average travel speed and urban street class. The following table illustrates LOS of urban street class with relation of average travel speed.

Urban street class	I	II	III	IV
Range of free-flow speed (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	50 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	>72	> 59	> 50	> 41
B	> 56-72	> 46-59	> 39-50	> 32- 41
C	> 40-56	> 33-46	>28-39	> 23-32
D	> 32-40	> 26-33	>22-28	> 18-23
E	> 26-32	> 21-26	>17-22	> 14-18
F	< 26	< 21	<17	< 14

Table 4.5: Urban street LOS by class (Source: HCM, 2000)

Referring Chapter 3 of this research, the urban street class of Lamberet Bus Station – Karalo route is urban street class IV (minor arterial) with speed limit of 40km/hr. HCM, 2000; states that if free flow speed cannot be measured in the field, the researcher might rely on the posted speed limit or some value around that limit. In this regard, the researcher takes the range of free flow speed of the route 45 Km/hr.

From section 4.2.2, the average travel speed of left lane is 12.82 km/hr, middle lane is 24 km/hr and the average travel speed of outer lane is 18.45 km/hr. Therefore, the LOS of the study route lanes can be obtained by relating urban street class of the study route with average travel speed of each lanes from the above table 4.5. Doing that, the LOS of left lane is **F**, middle lane is **C** and LOS of outer lane is **D**.

4.3. Vehicular Composition

This section presents the vehicular composition within the 1.0 km length of the Lamberet Bus Terminal – Karalo route at the peak hour; 8:00 am – 9:00 am. Table 4.4 below illustrates peak hour vehicle numbers with corresponding compositions on straight through lanes of the study route.

Types of vehicles	No. of vehicles	Composition (%)
Small car	954	74.07
Taxi	256	19.87
Bus	29	2.25
Medium-Bus	35	2.72
Truck	14	1.09
Aggregate	**1288**	**100.00**

Table 4.6: Peak hour vehicle composition of straight through lanes

The following figure depict the percentage composition of small car, taxi, bus, medium-bus and truck on the study route.

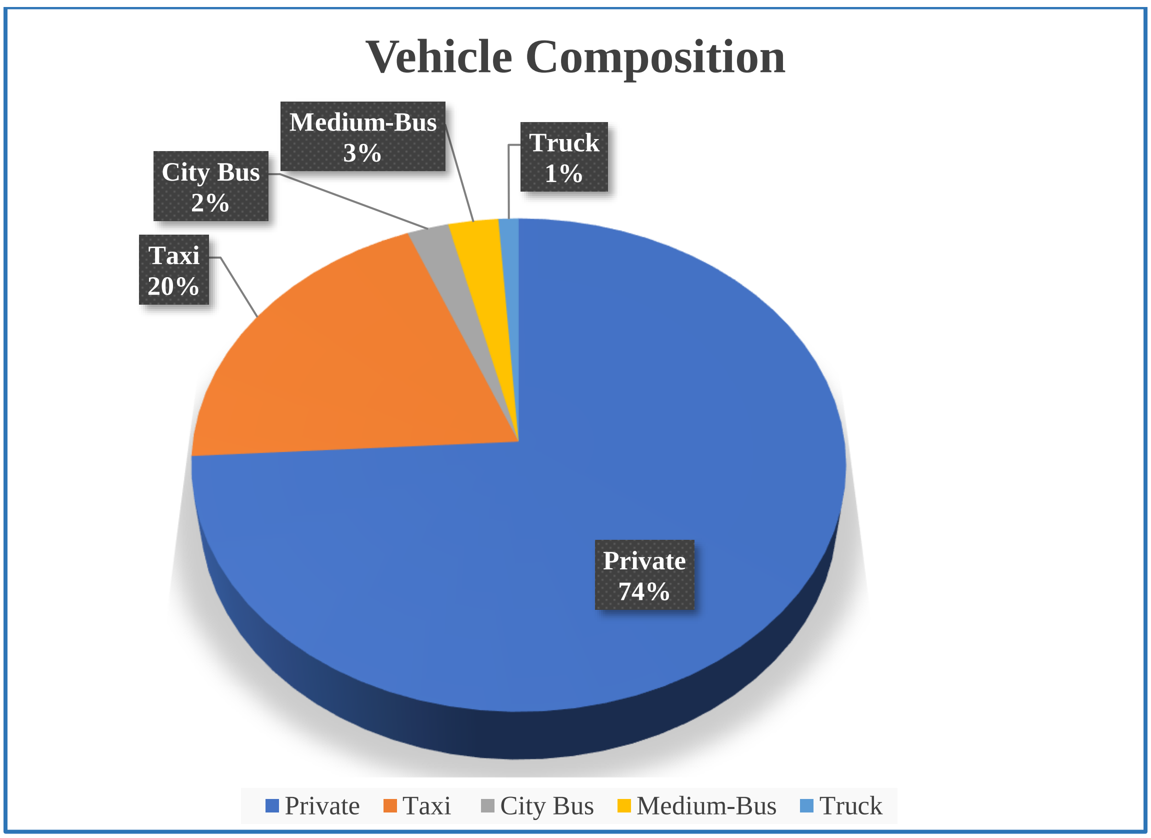


Figure 4.1: Peak hour vehicle share of straight through lanes

4.3.1. Vehicle Occupancy

As stated in the Bureau of Transportation Statistics dictionary, vehicle occupancy is the number of persons, including driver and passenger(s) in a vehicle which also includes persons who didn't complete a whole trip (www.transportation-dictionary.org)

Referring section 3.5, the researcher observed most private cars have only the driver and sometimes two passengers including the driver, and almost all taxies, city buses and medium buses carry more than their capacity. Therefore, based on the pilot study and observations, this research takes the number of persons in private car as two (2) and instead of averaging legal seat number of different city buses and medium buses, the researcher takes large legal seat number among different city buses and medium buses. Number of passengers in taxis taken based on their legal seat numbers of dolphin taxies because those taxies carry large passengers as compared to other taxies.

As depicted in Table 4.4, out of 1,288 vehicles, 954 are private cars, 256 are taxies, 29 are city buses, and 35 are medium buses. The city buses are Anbessa bus, Sheger bus and Alliance bus. Anbessa bus has a capacity of 100 passengers, Sheger bus has a capacity of 80 passengers and Alliance bus has a capacity of 60 passengers. The average occupancy of the city buses is 80 passengers but, since all city buses carry more than their capacity, instead of average occupancy the researcher took Anbessa buses carrying capacity, 100 passengers; for all city bus. This is because to include the number of passengers on the buses that carried more than their capacity. Table 4.5 below and subsequently figure 4.2 present the number of persons by vehicle types and vehicle compositions (%) respectively.

Type of vehicle	No of persons in a vehicle	No. Vehicle	Composition (%)	Total no of persons	Composition (%)
Private car	2	954	100%	1,908	17.6
Taxi	18	256	100%	4,608	42.6
City bus	100	29	100%	2,900	26.8
Medium bus	40	35	100%	1,400	13
Aggregate		**1,288**	**100%**	**10,816**	**100%**

Table 4.7: Number of persons in each vehicle type at peak hour

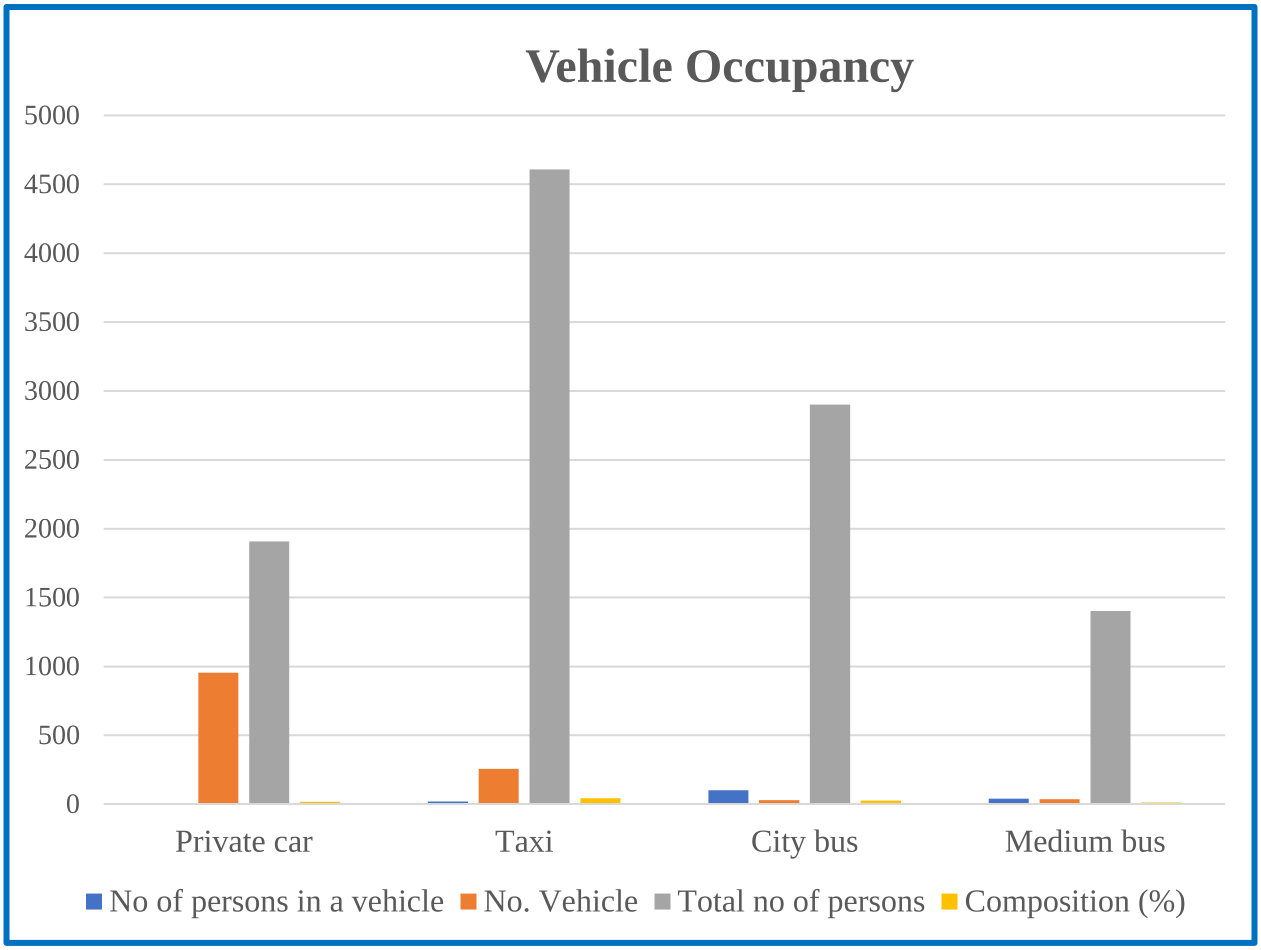


Figure 4.2: Vehicle occupancy of straight through lanes at peak hour.

4.4. Lane selection

The Lamberet Bus Station – Karalo route has two straight through lanes on one side. In this research, among those two straight through lanes, one lane was chosen as HOV lane during morning peak hour on weekdays only. Since HOV lanes are targeted to give the maximum benefits to vehicle owners with 4+ passengers and so, the lane with the highest number of taxis, city buses and medium buses was selected for analysis in this study. Having said this, from counted data, outer lane has large number of vehicles: taxis, city buses, medium buses as compared to the middle lane. Therefore, outer lane is chosen for HOV lane simulation.

4.5. Simulation Result

The advantages of simulating the real-life corridor include to capture various measures of performance such as traffic distribution per lane, vehicle speeds per lane, number of lane changes, travel times for automobiles and trucks and traffic queue lengths at critical merge and diverge points. (Siuhi, 2006)

The simulation was conducted using the VISSIM 9.0 Student Version software. VISSIM software has number of functions such as preferential treatment solutions for buses (e.g. bus-only lanes, HOV lanes, queue jumps), private and public transport operations under constraints of lane configuration, vehicle composition, traffic signals and public transport stops have been evaluated with VISSIM. In addition, pedestrian flows can be modeled either exclusively or combined with private traffic or public transport. In general, VISSIM software is a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness whereas the student version software has limited with 1km link length and 600sec simulation period.

The input data given for the VISSIM were number of lane, link length, traffic volume composition, and assumed desire speed. The input data were analyzed using vehicle travel time trajectory, public transport line, public transport stop and simulation tools. The simulation result output for evaluation of the performance of the HOV lane on the study route were number of high occupancy vehicles, average travel time and average travel speed**.**

The following figure shows the study route interface on VISSIM 9.0 software.

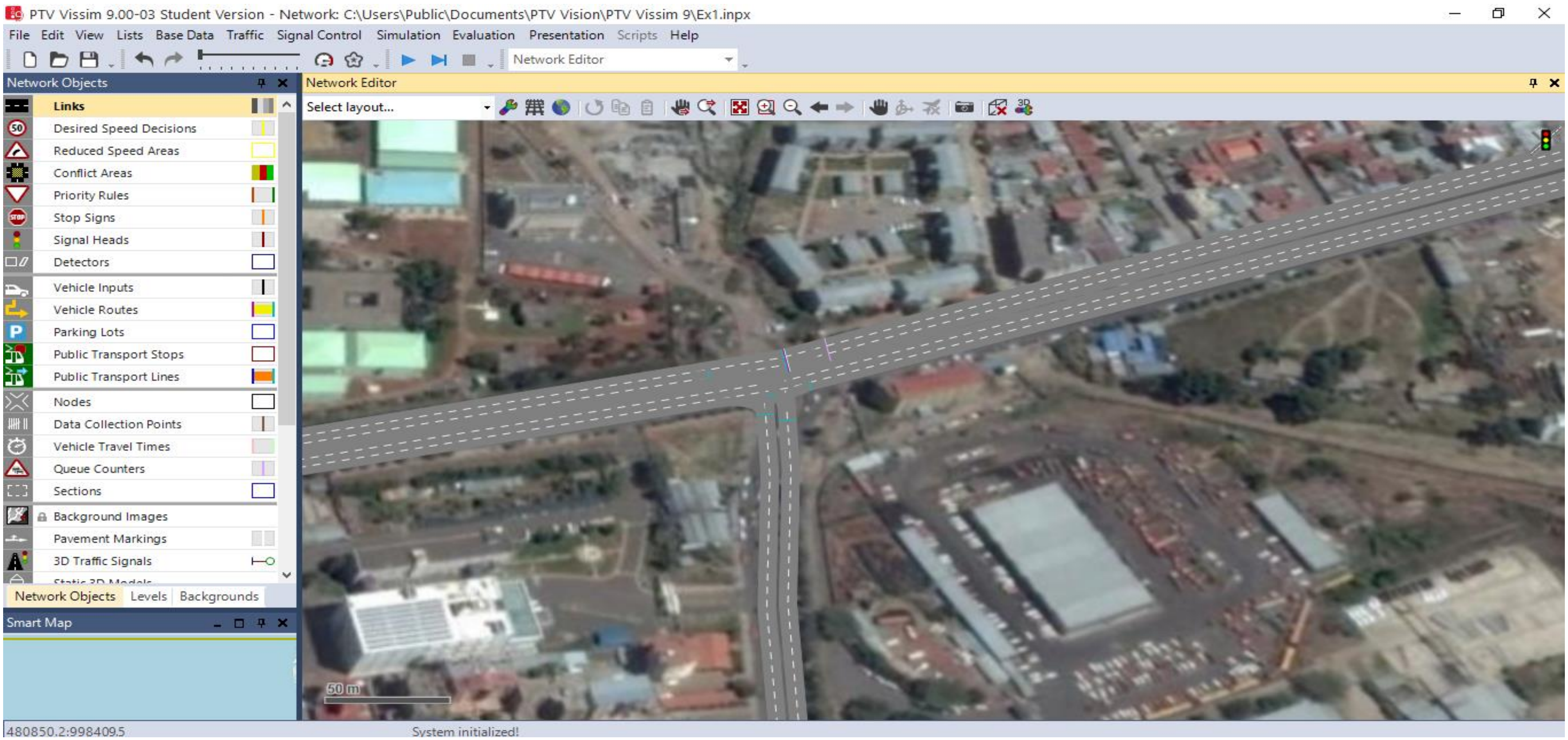


Figure 4.3:- Study route on VISSIM 9.0 software

The VISSIM simulation outputs were used to evaluate the travel efficiency of the HOV lane frome travel time and travel speed aspect and then to validate lane dedication section stated in Chapter 3. On the simulation, middle and outer lanes of the route were evaluated individually to be dedicated or restricted for purpose of HOV lane.

The VISSIM outputs used as good indicators were travel time and speed variance between restricted and non-restricted lanes. It is worth mentioning at this juncture that cars and trucks were restricted in the VISSIM simulation model from traveling on the restricted lanes since both cars and trucks cannot carry more than four passengers.

The following sections discuss HOV lane evaluation according to travel time and travel speed in detail.

4.5.1. Evaluation of Travel Time and Travel Speed

In section 4.2.1 and 4.2.2, calculations regarding field average travel time and travel speed of vehicles on straight through lanes were discussed. In this section, the simulation and outputs of average travel time and travel speed of vehicles on straight through lanes using VISSIM software will be discussed. Lane width, vehicle composition, vehicle input (peak hour traffic flow) and desired speed were input data that were used in the VISSIM software. Those input data were processed using vehicle travel times detector, public transport line, public transport stop and simulation tools.

The results of the simulation were approximates with field measured data. It is worth to mention that the travel times in the field were collected using video recording at two locations registering vehicles travel times from origin to destination from the recorded video. Travel time of both straight through and left lane vehicles that traversed the segment were used in the travel time aggregation.

The following table shows straight through lanes average travel time and travel speed. The field measured travel times and the calculated average travel speed were included in the table as a form of validation of the simulation results.

		Field Measurement			VISSIM Simulation Result		
Lane	Type of Vehicles	Travel length (Km)	Average travel time (hr)	Average travel speed (hr)	Travel length (Km)	Average travel time (hr)	Average travel speed (hr)
Left lane	Car	1.00	0.0727	13.75	1.00	0.0716	13.96
	HOVs	1.00	0.0930	10.75	1.00	0.0762	13.12
Middle Lane	Car	1.00	0.0366	27.32	1.00	0.0335	29.85
	HOVs	1.00	0.0468	21.36	1.00	0.0385	25.97
Outer Lane	Car	1.00	0.0437	22.88	1.00	0.0465	21.50
	HOVs	1.00	0.0648	15.43	1.00	0.0489	20.44

Table 4.8: Field and software result by car type

	Field Measurement			VISSIM Simulation Result		
Parameters	Left lane	Middle lane	Outer lane	Left lane	Middle lane	Outer lane
Travel length (Km)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Average travel time (hr)	0.0790	0.0373	0.0448	0.0722	0.0343	0.0475
Average travel speed (Km/hr)	12.82	26.76	22.32	13.85	29.15	21.05
Level of service (LOS)	F	C	D	F	C	D

Table 4.9: Field and software result by lane

Since it is difficult to get absolute exact values, the results in the above table validates the VISSIM simulation output and field measurement result of average travel time and travel speed of both straight through lanes. In addition, the results are validated from the Level of service (LOS) aspect.

4.5.2. HOV Lane Simulation

Preferential lanes are lanes designated for special traffic uses such as high occupancy vehicles (HOVs), light rail, buses, taxis, or bicycles. Preferential lane treatments might be as simple as restricting a lane to a certain class of vehicles during peak periods, or as sophisticated as providing a separate roadway system within a highway corridor for certain vehicles (MMUTCD, 2015).

In this section, outer lane and middle lane are restricted during morning peak hour period individually for HOV lane purpose. When outer lane restricted for HOV lane purpose, left lane and middle lane keep serving as a general-purpose lane, similarly when middle lane is restricted for HOV lane purpose, the left lane and outer lane give general-purpose lane service.

The lanes are evaluated based on number of high occupancy vehicles traveled within 600 sec of simulation period on the lane and the travel time taken by the high occupancy vehicles (vehicles which carry 4+ passengers) to complete the HOV lane. Table 4.10 below shows VISSIM simulation evaluation result of middle lane restricted for HOV lane purpose.

Table 4.10: Middle lane restriction evaluation from VISSIM simulation

HOV Lane	Number of High Occupancy vehicles	Travel length (Km)	Travel time (hr)	Average Travel Speed (km/hr)
Middle lane	35	1.0000	0.0362	27.62

To interpret the results of the above table, when the middle lane is restricted for high occupancy vehicles, the lane serves 35 high occupancy vehicles with 0.0362 hr of travel time and 27.35 average travel speed. On the simulation, the high occupancy vehicles such as taxi and buses changed their lane to the outer lane to stop at their station which reduced the vehicles’ travel times and speeds. 15.43

Table 4.11 below shows VISSIM simulation evaluation results when outer lane was restricted for HOV lane.

HOV Lane	Number of High Occupancy vehicles	Travel length (Km)	Travel time (hr)	Average Travel speed (km/hr)
Outer lane	48	1.00	0.0315	31.74

Table 4.11: Outer lane restriction evaluation from VISSIM simulation

Discussing the results in Table 5.4 above, because the outer lane is restricted for high occupancy vehicles, the lane serves 48 high occupancy vehicles with 0.0315 hour of travel time and 32km/hr average travel speed. Compared to the results that were obtained when the middle lane was restricted, the outer lane give service for 13 additional high occupancy vehicles with short travel time and better average speed.

In order to see the benefit of HOV lane restriction, it is must to compare the result with the existing condition. The following tables depicted comparison of existing lane and restricted HOV lane with comparison parameters of number of high occupancy vehicles, average travel time and average travel speed.

Middle Lane		
Comparison parameters	Existing lane condition	HOV lane condition
Number of HOVs	36	35
Average travel time (Hr.)	0.0468	0.0362
Average travel speed (Km/hr.)	21.36	27.62

Table 4.12: Comparison of existing middle lane and middle HOV lane

As showed on Table 4., before the middle lane restricted for HOV lane, the lane has been given service for 36 high occupancy vehicles with 21.36 km/hr average travel speed. But when the lane restricted for HOV lane, 35 HOVs served with 27.62 Km/hr average speed.

Therefore, regarding average travel time and average speed, as compared to the existing condition, the HOV lane average travel time and average speed higher with 0.0148 Hr and 6Km/hr respectively. Table 4.13 below shows comparison of existing and HOV lane condition of the outer lane.

Outer Lane		
Comparison parameters	Existing lane condition	HOV lane condition
Number of HOVs	43	48
Average travel time (Hr.)	0.0648	0.0315
Average travel speed (Km/hr.)	15.43	31.74

Table 4.13: Comparison of existing outer lane and outer HOV lane

As depicted on Table 4.9, before the outer lane restricted for HOV lane, the lane has been given service for 43 high occupancy vehicles with 15.43 km/hr average travel speed. On the other hand, when the lane restricted for HOV lane, 48 HOVs served with 31.74 Km/hr average speed.

From the comparison, the HOV lane condition of the outer lane shows significant improvement regarding number of HOVs, average travel time and average travel speed.

Therefore, based on the HOV lane evaluation and comparison result, the outer lane is preferable for High Occupancy Vehicle lane.

4.5.3. Effect of HOV lane on the performance of general-purpose lanes

The dedication of HOV lane for high occupancy vehicles has its own effect on the general-purpose lane. During the non HOVs flow of the dedicated HOV lane divert to the general-purpose lane, the level of service of the general-purpose lane might be drop off.

When outer lane is dedicated for HOV lane, it is expected that middle and left lane to carry the outer lane traffic flow excluding HOVs. Similarly, when the middle lane is dedicated for HOV lane, its non HOVs traffic flow expected to be diverted on the left and outer lanes. But as shown on Table 4.9, the left lane has F level of service which lessen the expectancy of serving the diverted traffic from middle and outer lanes.

Therefore, when outer lane is dedicated for HOV lane, the middle lane would be a general-purpose lane and serve its own traffic flow in addition with non HOVs traffic flow of outer lane. On the other hand, when a middle lane restricted for HOV lane, the outer lane serves as a general-purpose lane. The following tables depicted the effect of HOV lane on the performance of general-purpose lanes.

	Outer HOV lane		
General purpose lane	Average travel time (Hr.)	Average travel speed (Km/hr.)	LOS
Middle lane	0.0497	20.12	D

Table 4.14: Effect of outer HOV lane on performance of middle general-purpose lane

The above Table 4.14 shows the effect of HOV lane while the middle lane performing as a general-purpose lane. On section 4.4, Table 4.9, the existing level of service of the middle lane before being the only general-purpose lane was C.

From the simulation result, when the middle lane carried its own traffic flow in addition with outer lane's non HOVs traffic flow, its level of service lowered from C to D.

	Middle HOV lane		
General purpose lane	Average travel time (Hr.)	Average travel speed (Km/hr.)	LOS
Outer lane	0.0792	12.62	F

Table 4.15: Effect of middle HOV lane on the performance of outer general-purpose lane

Similarly, the above Table 4.15 shows the effect of middle HOV lane on the performance of non HOV lane. The existing level of service of the outer lane was D.

Both HOV lanes has lowered the performance of non-HOV lanes. But comparing the outer HOV lane with middle HOV lane, dedicating the middle lane for HOV lane purpose has affected the non-HOV lane traffic flow to the worst. In addition, unlike outer HOV lane, the middle HOV lane performance evaluation doesn't show significant average speed change for high occupancy vehicles.

Therefore, regarding the performance of general purpose lane, outer HOV lane dedication is preferable from level of service aspect.

4.5.4. HOV Lane Sign

HOV lane has its own standard road side sign and pavement marking. Based on Minnesota Manual on Uniform Traffic Control devices (MMUTCD, 2015), the pavement marking of HOV lane is a diamond sign and when the vehicle occupancy required for use of an HOV lane, it is then varied as a part of a managed lane operational strategy; regulatory signs that include changeable message elements that shall be used to display the required vehicle occupancy in effect. In this research, the vehicle occupancy requirement applicable to an HOV lane is 4 or more passengers per vehicle and the periods of operation is from 8:00 am – 9:00 am in the morning on weekdays. Therefore, regarding the requirement, there are a number of regulatory HOV lane signs in MMUTCD hand book.

The following signs are taken from MMUTCD handbook for utilization in this research. Figure 4.4 illustrates the road sign for HOV lane with reference to the MMUTCD, (2015)

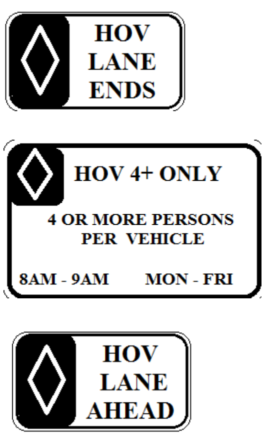


Figure 4.4: Road sign for HOV lane

Figure 4.5 below illustrates the road side sign of HOV lane that resulted from VISSIM simulation.

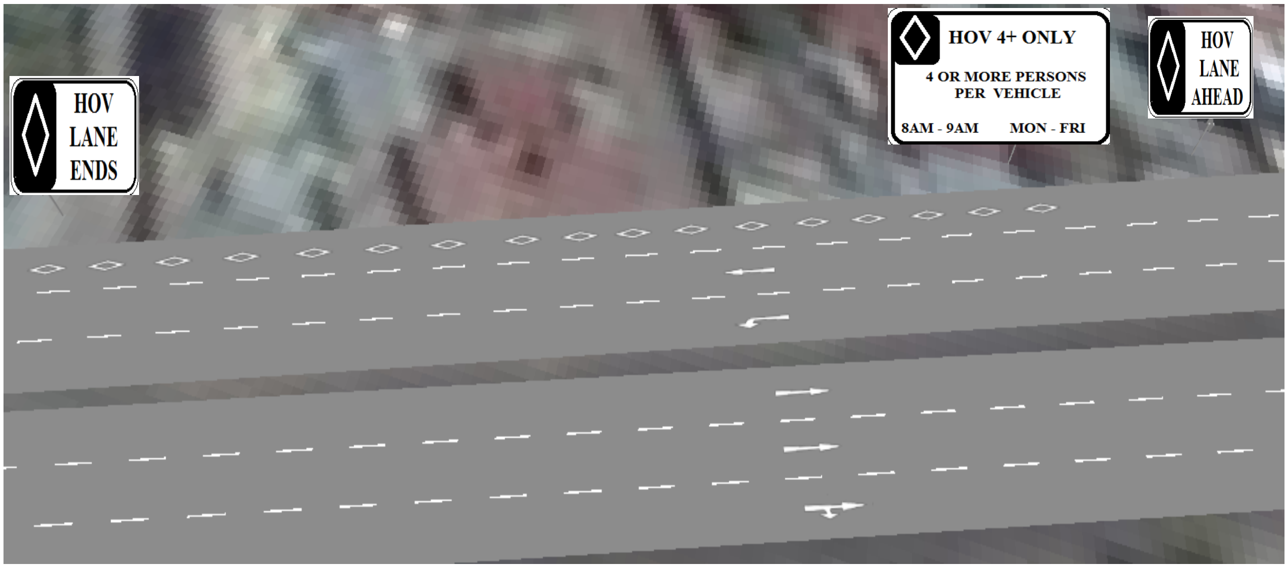


Figure 4.5: Road side sign of HOV lane on HOV lane from VISSIM simulation

4.5.5. HOV Lane Enforcement Techniques

Enforcement is very important to the successful operation of the proposed HOV lane facility. The main purpose of HOV lane enforcement is to protect the lane and prevent possible violators and promote the safe and efficient use of the HOV lanes. Since HOV lane is new for Ethiopia, the country doesn't have enforcement policy that focuses on HOV lane violation. In developed countries like the United States of America, there are a number of road side detection techniques that sense HOV lane violators. Some of the techniques are video systems, infrared systems, passive microwave systems, safety belts, weight sensor, optical system, capacitive sensor, radar sensor, smart cards and readers.

Even if it would be expensive to adapt those technologies for Ethiopia, the researcher suggestion is to first give public awareness for the road users and traffic polices about the purpose and rules of HOV lane and assign those traffic polices to enforce HOV lane violators. In addition, the video technology also more effective to detect the HOV lane violators.

CHAPTER 5

CONCLUSION, RECOMMENDATIONS AND PROPOSED FUTURE RESEARCH AREAS

5.1. Conclusion

The purpose of this research study was to evaluate the performance of HOV lane traffic management technique to improve travel time and travel speed of high occupancy vehicles. The study corridor was Lamberet bus terminal – Karalo route in Addis Ababa spanning 5.4 km. This corridor has four straight through, left & right lanes in both northbound and southbound directions.

On the study corridor, the causes of commuting hour traffic congestion are, presence of the Lamberet Bus Terminal, absence of ride-sharing, because of not giving priority to vehicles on the major road, poor traffic management techniques, accidents occurring at merging points exacerbate congestion, presence of truck vehicles, blocking lanes while trying overtaking and, presence of un-signalized intersection.

In this study, both primary and secondary data that were relevant for achieving the objectives of the research were collected. The collected data were analyzed in two ways; hand analysis and software analysis. Even if, Average travel time and average travel speed results that obtained from hand analysis and VISSIM software simulation were not absolute exact, the results of both hand and software analysis were validated from level of service (LOS) aspect.

The HOV lane restriction was only operational during the morning peak 8 a.m. to 9 a.m. because off peak hour traffic flow is not congested. The performance evaluation measurements used in this study were number of high occupancy vehicles, average travel time and speeds for high occupancy vehicles.

In this study, HOV lane restriction scenario was built in the VISSIM simulation model for the evaluation of performance efficiency in the study corridor. In the VISSIM simulation model, small cars and trucks were restricted from the straight through lanes to simulate the HOV lane performance for high occupancy vehicles which carry more than 4 passengers in the study corridor. The simulations were performed for peak 8 a.m. to 9 a.m. hour traffic flow. Furthermore, two alternative HOV lane restriction scenarios involved middle lane and outer lane restriction were simulated to determine which lanes should be restricted to improve performance operations for high occupancy vehicles.

The performance of HOV lane restrictions on middle and outer through lane was analyzed using the number of high occupancy vehicles served, time and speed differences among lanes.

The simulation results showed that during peak traffic flow conditions, high occupancy vehicles gained significantly more travel time savings due to the restriction of automobiles and trucks from using the outer lane. The analysis of travel time and speed per lane indicated that the outer lane, from which small cars and trucks are restricted, had higher speeds and short travel time as compared to middle lane restriction as well as non-restricted lanes.

In addition, the effect of HOV lane on the performance of general purpose (non-HOV) lanes were simulated. Unlike the outer HOV lane, middle HOV lane dedication affect the performance of non-HOV lane to the worst.

Based on those simulation results, it can fairly be concluded the outer HOV lane dedication for high occupancy vehicles has significant performance benefits with respect to travel time reduction and increase average speed during peak hour congested traffic conditions.

5.2. Recommendations

Based on the findings of this study, the following points are forwarded to reduce congestion on Lamberet Bus Terminal – Karalo route and for replication on other similar urban roads: -

These are:

- Dedicating the outer lane of the study corridor for HOV lane purpose at morning peak hour is recommended to reduce travel time as well as to increase travel speed of public transport users.
- Use of public transportation with high occupancy is preferred to private vehicles from travel time aspect, although not sufficiently available on the study route, as well as on other routes in Addis Ababa.
- Since during peak hour public transports carry more than their capacity, Government must provide required number of public transport.
- AACRA and other organizations who work on Road and Transport issues should give emphasis on applying alternative traffic congestion reduction traffic management techniques that reduce travel time of passengers such as HOV lane;

5.3. Proposed future research areas

The following are proposed for future research:

- The findings of this research exhibited the performance of HOV lane in respect of travel time and travel speed. The research was done on one km of a road segment. However, for future work, a longer segment is recommended to fully comprehend the effect of minimization of traffic congestion on road users' time, vehicle operating costs and fuel consumption and;
- Performance evaluation of HOV lane and Bus Rapid Transit (BRT) lane.

REFERENCE

- Abiy Zegeye, Alemayehu Worku, Daniel Tefera, Melese Getu & Yilma Sileshi. *"Introduction to research methods"* Graduate Studies and Research Office Addis Ababa University, September 2009.
- Addis Ababa Road Authority (AACRA), "*Section 4: Applications of Design principles & Standards"*, September 2004.
- Addis Ababa Road Authority (AACRA) Geometric Design manual , "*Semen Terminal – Karalo Road Project*", February 2003.
- Adolf D. May, "*Traffic Flow Fundamentals*" Prentice-Hall, Inc., 1990.
- Brandon, "*8 Pros and Cons of Carpooling*" Aug 11, 2015. Accessed on April 2017. https://brandongaille.com/8-pros-and-cons-of-carpooling/
- Brook Abdu, Fortune's staff writer, *"Mass Transportation Mess: The Poor Traffic Management in Addis Ababa"*. Fortune, Jun 22, 2015: [Vol 16, NO 790]
- Bureau of Transportation Statistics, "*Vehicle Occupancy*", 2008. Accessed on June 8, 2017. www.transportation-dictionary.org/vehicle_occupancy
- Bourns College of Engineering, Center for Environmental Research and Technology, "Modeling the Effectiveness of High Occupancy Vehicle (HOV) Lanes at Improving Air Quality", Dec 2006. University of California, River side, CA 92521
- C Dixon and K Alexander, *"Literature Review of HOV lane Schemes"* March 2005.
- Cyulberg & Eldon L. Jacobson, *"HOV lane enforcement evaluation"* January 1993.
- Dr. Harish M. *"Urban Transport and Traffic Management - For Sustainable Transport Development in Mysore City".* International Journal of IT, Engineering and Applied Sciences Research, Volume 2, No. 3, March 2013.
- Federal-Aid Highway Program Guidance on HOV lane, "*Glossary of Terms*", September 2016

- FHWA, U.S Department of Transportation report. "*A Review of HOV Lane Performance and Policy Options in the United States*" December 2008.
- Florida Department of Transportation, *"Traffic Analysis Handbook: A reference for Planning and Operations"*, Systems Planning Office, March 2014.
- Ilias Leontiadis, Gustavo Marfia, David Mack, Giovanni Pau, Cecilia Mascolo and Mario Gerla. *"On effectiveness of an opportunistic traffic management system for vehicle networks."*
- Jaimyoung Kwon & Pravin Varaiya, *"Effectiveness of High Occupancy Vehicle (HOV) Lanes in the San Francisco Bay Area"* Department of Statistics California State University, East Bay Hayward and Department of Electrical Engineering and Computer Science University of California, Berkeley.
- Joshua Bauer, *"High Occupancy Vehicle Lanes- An Overall Evaluation including Brisbane Case Studies".* Australian Institute of Traffic Planning and management, 2005.
- Joy Dahlgren, "*Are HOV Lanes Really Better*" Number 9, Spring 1995. Accessed on April 2017. http://www.accessmagazine.org/articles/spring-1995/
- Joseph. O. Ukpata & Anderson A. Etika. "*Traffic Congestion in Major Cities of Nigeria"* International Journal of Engineering and Technology Volume 2 No. 8, August 2012.
- Kitae Jang, Koohong Chung, David R. Ragland & Ching -Yan Chan "*Safety Performance of High-Occupancy Vehicle (HOV) Facilities: Evaluation of HOV Lane Configurations in California*". Safe Transportation Research & Education Center (SafeTrec), January 2009
- Kumares C. Sinha, Louis F. Cohn, Chris T. Hendrickson, and Yorgos Stephanedes. *"Role of Advanced Technologies in Transport Engineering"*, June 2012.
- LiquiSearch, "*High-occupancy Vehicle Lane – History*", 2017, Accessed on March 2017. http://www.liquisearch.com/high-occupancy_vehicle_lane/history
- Martin Rogers, "*Highway Engineering*" Department of Civil and Structural Engineering, Dublin Institute of Technology, Ireland, 2003.

- Minnesota Department of Transportation, "*Minnesota Manual on Uniform Traffic Control Devices (MMUTCD)*", February 2015.
- Monwar Mahmood, Mohammad Abul Bashar & Salma Akhter. "*Traffic Management System and Travel Demand Management (TDM) Strategies: Suggestions for Urban Cities in Bangladesh*" M. Mahmood et al. / Asian Journal of Management and Humanity Sciences, Vol. 4, No. 2-3, 2009.
- Moving Technology (MC Trans), "*Traffic System Integrated Software – Corridor Simulation*". Accessed on March 2017. http://www.mctrans.ce.ufl.edu
- NCHRP Report 414, "*HOV Systems Manual*". Texas Transportation Institute, The Texas A&M University System, College Station, Texas, Parsons Brinckerhoff Quade and Douglas, Inc., Orange, California, Pacific Rim Resources, Inc., Seattle, Washington,1998.
- Nevada Department of Transportation. *"comparative evaluation of simulation software for traffic operation"*, December 2002.
- Olaogbebikan Jimoh Eniola, Akinsulire Esther Seun and Enosko Okoko. *"Traffic Management Problems in Lagos: A Focus on Alaba International Market Road, Ojo, Lagos State Nigeria"* Journal of Economics and Sustainable Development Vol.4, No.4, 2013
- Oyadiran Phillip A. & Aregbesola Adewumi M. "Road Transport Policy and Traffic Management in Nigeria" Journal of Research in National Development: Volume 6, No 1, June 2008.
- Peter T. Martin, Joseph Perrin & Pen Wu and Rob Lambert "Evaluation of the Effectiveness of High Occupancy Vehicle Lanes" University of Utah: May 2004.
- PF Collins International Trade Services, "*Transportation Best practice manual*", May 2003
- P.M. Xavier, Raju Nedunchezhian, "*Comparative study on road traffic management systems"*. International Journal of Research in Engineering and Technology Volume: 03 Special Issue: December 2014.
- PTV Group, "*PTV VISSIM 9 user manual*", PTV AG, Karlsruhe, Germany, 2016.

- Saidi Siuhi, "*Simulation analysis of truck restricted and HOV lanes*". Florida State University Libraries, November 2006.
- Snorre Laegran, *"Re-allocation Road Space: Introducing HOV-Lane in City of Trondheim"*, November 2001.
- State of California, "*High Occupancy Vehicle Systems*", 2017, Accessed on March 2017. http://www.dot.ca.gov/trafficops/tm/hov.html
- SYSTRA, "PARAMICS Microsimulation", 2016, Accessed on April 2017. http://www.sias.com/sp/sparamicshome.htm
- The Federal Democratic Republic of Ethiopia Ministry of Transport, "*Transport policy of Addis Ababa*", August 2011
- Transportation Research Board, *"Highway Capacity Manual"*. National Research Council, 2000.
- U.S. Department of Transportation, Federal Highway Administration, "*Corridor Simulation (CORSIM/TSIS)*", February 5, 2017.
- Urban Transportation Showcase Program, "*High Occupancy Lane in Canada*", December 2007.
- William H. K. Lam. "*Traffic control and management-recent methodological advances*". Journal of advanced Transportation, Wiley Online Library: December 2012.
- World Bank report, "*Addis Ababa, Ethiopia Enhancing Urban Resilience*" July 2015.

ANNEXES

ANNEX A: Recorded traffic flow

Monday 7:30 -7:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	128	91	87
Taxi	15	20	17
City Bus	0	2	3
Medium Bus	2	1	4
Truck	0	0	2
	145	114	113
7:45 – 8:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	131	97	93
Taxi	19	18	21
City Bus	1	0	3
Medium Bus	0	2	5
Truck	0	0	0
	151	117	122
8:00 – 8:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	136	115	92
Taxi	23	25	19
City Bus	3	0	4
Medium Bus	0	2	5
Truck	4	1	2
Total	166	143	132
8:15 – 8:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	148	131	106
Taxi	19	44	28
City Bus	0	2	4
Medium Bus	2	0	12
Truck	2	1	3
	171	178	166
8:30 – 8:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	133	129	125
Taxi	23	40	26

City Bus	4	1	3
Medium Bus	7	1	5
Truck	2	2	1
	169	173	170
8:45 – 9:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	141	137	157
Taxi	21	11	9
City Bus	1	1	3
Medium Bus	3	0	4
Truck	0	0	0
	166	149	173
9:00 – 9:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	124	123	134
Taxi	13	13	10
City Bus	1	0	2
Medium Bus	1	2	1
Truck	0	0	0
	139	138	147
9:15 – 9:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	117	126	139
Taxi	13	10	9
City Bus	1	2	1
Medium Bus	0	2	1
Truck	0	1	0
	131	141	150

Table A1: Traffic flow on Monday

Tuesday 7:30 -7:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	54	59	51
Taxi	14	17	22
City Bus	1	0	1
Medium Bus	0	0	0
Truck	1	1	1
	70	77	75
7:45 – 8:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	67	79	61
Taxi	9	12	17
City Bus	1	1	1
Medium Bus	1	0	2
Truck	2	1	1
	80	93	82
8:00 – 8:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	74	77	47
Taxi	9	12	32
City Bus	0	0	3
Medium Bus	0	1	4
Truck	3	3	1
	86	93	87
8:15 – 8:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	131	133	109
Taxi	16	15	22
City Bus	2	0	1
Medium Bus	3	1	6
Truck	8	3	2
	160	152	140
8:30 – 8:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	123	135	83
Taxi	20	24	45

City Bus	3	1	2
Medium Bus	1	1	4
Truck	9	7	6
	156	168	140
8:45 – 9:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	138	135	75
Taxi	14	23	52
City Bus	0	3	1
Medium Bus	1	4	7
Truck	4	4	4
	157	169	139
9:00 – 9:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	72	127	78
Taxi	9	22	45
City Bus	0	2	0
Medium Bus	1	1	4
Truck	0	1	1
	82	153	128
9:15 – 9:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	62	57	67
Taxi	5	7	33
City Bus	0	0	0
Medium Bus	1	1	2
Truck	0	1	1
	68	66	103

Table A2: Traffic flow on Tuesday

Wednesday 7:30 -7:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	68	72	63
Taxi	10	11	9
City Bus	2	2	2
Medium Bus	1	0	1
Truck	0	3	1
	81	88	76
7:45 – 8:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	65	81	69
Taxi	17	7	12
City Bus	2	4	3
Medium Bus	0	0	0
Truck	0	2	0
	84	94	84
8:00 – 8:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	77	87	76
Taxi	17	12	13
City Bus	3	2	4
Medium Bus	1	1	1
Truck	0	5	3
	98	107	97
8:15 – 8:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	88	91	85
Taxi	19	8	17
City Bus	2	2	1
Medium Bus	1	0	2
Truck	2	4	3
	112	105	108
8:30 – 8:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	122	105	89
Taxi	27	10	23
City Bus	2	1	3
Medium Bus	4	1	2

Truck	4	4	1
	159	121	118
8:45 – 9:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	75	97	81
Taxi	23	11	16
City Bus	2	0	2
Medium Bus	1	2	0
Truck	2	4	2
	103	114	101
9:00 – 9:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	76	96	73
Taxi	16	8	12
City Bus	1	0	3
Medium Bus	1	0	1
Truck	0	3	1
	94	107	90
9:15 – 9:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	69	88	69
Taxi	17	9	15
City Bus	2	1	1
Medium Bus	0	0	2
Truck	0	1	0
	88	99	87

Table A3: Traffic flow on Wednesday

Thursday 7:30 -7:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	83	64	39
Taxi	10	24	27
City Bus	0	3	5
Medium Bus	4	1	1
Truck	6	0	1
	103	92	73
7:45 – 8:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	102	73	42
Taxi	7	21	33
City Bus	0	2	4
Medium Bus	1	0	0
Truck	2	1	2
	112	97	81
8:00 – 8:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	101	80	45
Taxi	10	25	29
City Bus	2	1	5
Medium Bus	1	2	9
Truck	13	9	5
	127	117	93
8:15 – 8:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	110	76	41
Taxi	8	19	22
City Bus	2	0	2
Medium Bus	2	3	6
Truck	8	5	7
	130	103	78
8:30 – 8:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	81	69	47
Taxi	9	21	26
City Bus	3	0	2
Medium Bus	7	4	2

Truck	13	8	7
	113	102	84
8:45 – 9:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	96	71	53
Taxi	21	15	25
City Bus	3	1	2
Medium Bus	4	2	3
Truck	1	5	4
	125	94	87
9:00 – 9:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	87	73	47
Taxi	8	11	24
City Bus	2	1	4
Medium Bus	1	0	1
Truck	0	4	0
	98	89	76
9:15 – 9:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	76	64	42
Taxi	13	13	21
City Bus	1	2	2
Medium Bus	0	0	0
Truck	1	1	0
	91	80	65

Table A4: Traffic flow on Thursday

Friday 7:30 -7:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	73	65	33
Taxi	11	18	16
City Bus	1	3	0
Medium Bus	2	1	2
Truck	0	9	0
	87	96	51
7:45 – 8:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	69	66	29
Taxi	9	25	20
City Bus	1	2	3
Medium Bus	0	0	0
Truck	4	14	0
	83	107	52
8:00 – 8:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	97	73	37
Taxi	13	25	21
City Bus	1	4	3
Medium Bus	2	2	2
Truck	4	11	4
	117	115	67
8:15 – 8:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	115	77	41
Taxi	20	29	19
City Bus	3	3	3
Medium Bus	2	1	0
Truck	8	7	3
	148	117	66
8:30 – 8:45 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	110	81	36
Taxi	23	23	18
City Bus	2	4	2
Medium Bus	2	4	1

Truck	7	7	7
	144	119	64
8:45 – 9:00 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	113	72	39
Taxi	16	23	13
City Bus	2	3	0
Medium Bus	4	4	1
Truck	4	5	5
	139	107	58
9:00 – 9:15 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	107	57	27
Taxi	9	13	11
City Bus	0	3	0
Medium Bus	1	1	0
Truck	1	0	2
	118	74	40
9:15 – 9:30 a.m.			
Vehicle Category	**Left lane**	**Middle lane**	**Outer lane**
Small car	78	43	23
Taxi	7	12	9
City Bus	2	0	0
Medium Bus	1	0	0
Truck	9	1	0
	96	56	32

Table A5: Traffic flow on Friday

ANNEX B: Peak hour traffic flow

The following tables show the peak hour traffic flow of 1Km segment which is a part of Lamberet Bus Terminal – Karalo route. The peak hour traffic flow of left lane, middle lane and outer lane are tabulated below.

Peak hour Morning Traffic volume of Left lane 8:00 am– 9:00 am			
Days of the week	Vehicle composition	Number	share in %
Monday	Car	563	83.78
	Taxi	78	11.61
	City bus	16	2.38
	truck	15	2.23
	Aggregate total	672	100.00
Days of the week	Vehicle composition	Number	share in %
Tuesday	Car	466	83.36
	Taxi	59	10.55
	City bus	10	1.79
	Delivery car	24	4.29
	Aggregate total	559	100.00
Days of the week	Vehicle composition	Number	share in %
Wednesday	Car	422	89.41
	Taxi	30	6.36
	City bus	7	1.48
	Delivery car	13	2.75
	Aggregate total	472	100.00
Days of the week	Vehicle composition	Number	share in %
Thursday	Car	391	78.99
	Taxi	35	7.07
	City bus	17	3.43
	Delivery car	52	10.51
	Aggregate total	495	100.00
Days of the week	Vehicle composition	Number	Share in %
Friday	Car	391	71.35
	Taxi	70	12.77
	Bus	16	2.92
	Delivery car	71	12.96
	Aggregate total	548	100.00

Table B-1: Peak hour traffic flow of left lane

Peak hour Morning Traffic volume of Middle lane 8:00 am– 9:00 am			
Days of the week	Vehicle composition	Number	share in %
Monday	Car	512	79.63
	Taxi	120	18.66
	City bus	7	1.09
	truck	4	0.62
	Aggregate total	643	100.00
Days of the week	Vehicle composition	Number	share in %
Tuesday	Car	480	82.47
	Taxi	74	12.71
	City bus	11	1.89
	Delivery car	17	2.92
	Aggregate total	582	100.00
Days of the week	Vehicle composition	Number	share in %
Wednesday	Car	380	85.01
	Taxi	41	9.17
	Bus	9	2.01
	Delivery car	17	3.80
	Aggregate total	447	100.00
Days of the week	Vehicle composition	Number	share in %
Thursday	Car	296	71.15
	Taxi	80	19.23
	City bus	13	3.13
	Delivery car	27	6.49
	Aggregate total	416	100.00
Days of the week	Vehicle composition	Number	share in %
Friday	Car	303	66.16
	Taxi	100	21.83
	City bus	25	5.46
	Delivery car	30	6.55
	Aggregate total	458	100.00

Table B-2: Peak hour traffic flow of middle lane

Peak hour Morning Traffic volume of Outer lane 8:00 am– 9:00 am			
Days of the week	Vehicle composition	Number	share in %
Monday	Car	314	62.06
	Taxi	151	29.84
	City bus	28	5.53
	truck	13	2.57
	Aggregate total	506	100.00
Days of the week	Vehicle composition	Number	share in %
Tuesday	Car	452	70.08
	Taxi	143	22.17
	City bus	40	6.20
	Delivery car	10	1.55
	Aggregate total	645	100.00
Days of the week	Vehicle composition	Number	share in %
Wednesday	Car	331	78.07
	Taxi	69	16.27
	City bus	15	3.54
	Delivery car	9	2.12
	Aggregate total	424	100.00
Days of the week	Vehicle composition	Number	share in %
Thursday	Car	186	54.23
	Taxi	102	29.74
	City bus	31	9.04
	Delivery car	24	7.00
	Aggregate total	343	100.00
Days of the week	Vehicle composition	Number	share in %
Friday	Car	153	60.00
	Taxi	71	27.84
	City bus	12	4.71
	Delivery car	19	7.45
	Aggregate total	255	100.00

Table B-3: Peak hour traffic flow of outer lane

ANNEX C: Travel time of vehicles on left, middle and outer lanes

Table C-1: Travel time of Small cars on left lane

	Left Lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
1	Car	0.0000	0.0208
2	Car	0.0019	0.0200
3	Car	0.0050	0.0189
4	Car	0.0056	0.0186
5	Car	0.0075	0.0181
6	Car	0.0078	0.0186
7	Car	0.0086	0.0194
8	Car	0.0089	0.0211
9	Car	0.0097	0.0208
10	Car	0.0117	0.0236
11	Car	0.0150	0.0414
12	Car	0.0164	0.0417
13	Car	0.0172	0.0469
14	Car	0.0183	0.0508
15	Car	0.0192	0.0525
16	Car	0.0197	0.0544
17	Car	0.0208	0.0600
18	Car	0.0219	0.0628
19	Car	0.0269	0.0658
20	Car	0.0283	0.0664
21	Car	0.0300	0.0681
22	Car	0.0308	0.0719
23	Car	0.0319	0.0725

Table C-1: Travel time of Small cars on left lane (cont'd)

	Left lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
24	Car	0.0328	0.0739
25	Car	0.0425	0.0658
26	Car	0.0531	0.0628
27	Car	0.0536	0.0492
28	Car	0.0542	0.0639
29	Car	0.0544	0.0661
30	Car	0.0553	0.0672
31	Car	0.0556	0.0689
32	Car	0.0578	0.0708
33	Car	0.0583	0.0719
34	Car	0.0592	0.0736
35	Car	0.0600	0.0775
36	Car	0.0614	0.0850
37	Car	0.0633	0.0861
38	Car	0.0653	0.0872
39	Car	0.0664	0.0894
40	Car	0.0672	0.0900
41	Car	0.0692	0.0894
42	Car	0.0708	0.0894
43	Car	0.0758	0.0894
44	Car	0.0775	0.0917
45	Car	0.0786	0.0922
46	Car	0.0797	0.0928
47	Car	0.0822	0.0931
48	Car	0.0850	0.0919

Table C-1: Travel time of Small cars on left lane (cont'd)

	Left lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
49	Car	0.0867	0.0919
50	Car	0.0875	0.0922
51	Car	0.0889	0.0925
52	Car	0.0903	0.0922
53	Car	0.0922	0.0917
54	Car	0.0942	0.0933
55	Car	0.0956	0.0936
56	Car	0.0972	0.0936
57	Car	0.0986	0.0942
58	Car	0.1000	0.0939
59	Car	0.1019	0.0931
60	Car	0.1031	0.0933
61	Car	0.1042	0.0939
62	Car	0.1053	0.0942
63	Car	0.1153	0.0886
64	Car	0.1175	0.0878
65	Car	0.1222	0.0842
66	Car	0.1233	0.0842
67	Car	0.1244	0.0844
68	Car	0.1269	0.0861
69	Car	0.1278	0.0869
70	Car	0.1283	0.0878
71	Car	0.1292	0.0878
72	Car	0.1394	0.0817
73	Car	0.1414	0.0811

Table C-1: Travel time of Small cars on left lane (cont'd)

	Left lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
74	Car	0.1428	0.0811
75	Car	0.1433	0.0819
76	Car	0.1447	0.0819
77	Car	0.1458	0.0822
78	Car	0.1467	0.0822
79	Car	0.1472	0.0831
80	Car	0.1492	0.0836
81	Car	0.1553	0.0842
82	Car	0.1592	0.0808
83	Car	0.1606	0.0806
84	Car	0.1622	0.0803
85	Car	0.1631	0.0808
86	Car	0.1672	0.0775
87	Car	0.1683	0.0775
88	Car	0.1694	0.0775
89	Car	0.1711	0.0769
90	Car	0.1719	0.0775
91	Car	0.1750	0.0758
92	Car	0.1758	0.0767
93	Car	0.1792	0.0747
94	Car	0.1808	0.0747
95	Car	0.1825	0.0744
96	Car	0.1833	0.0747
97	Car	0.1850	0.0747
98	Car	0.1858	0.0756

Table C-1: Travel time of Small cars on left lane (cont'd)

	Left lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
99	Car	0.1872	0.0747
100	Car	0.1883	0.0744
101	Car	0.1894	0.0742
102	Car	0.1931	0.0725
103	Car	0.1961	0.0703
104	Car	0.1975	0.0706
105	Car	0.1983	0.0706
106	Car	0.2000	0.0697
107	Car	0.2003	0.0706
108	Car	0.2017	0.0706
109	Car	0.2025	0.0711
110	Car	0.2067	0.0692
111	Car	0.2075	0.0700
112	Car	0.2083	0.0703
113	Car	0.2103	0.0706
		Travel Time	**8.2192**
		Average Travel Time	**0.0727**

Table C-2: Travel time of HOVs on left lane

	Left lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
1	Bus	0.0000	0.0544
2	Taxi	0.0236	0.0806
3	Taxi	0.0514	0.0744
4	Taxi	0.0611	0.0942
5	Taxi	0.0722	0.1028
6	Taxi	0.0731	0.1042
7	Taxi	0.0928	0.1072
8	Taxi	0.1147	0.1008
9	Taxi	0.1261	0.0992
10	Taxi	0.1300	0.1022
11	Bus	0.1306	0.1031
12	Taxi	0.1483	0.0967
13	Taxi	0.1500	0.0986
14	Taxi	0.1511	0.0994
15	Taxi	0.1522	0.0994
16	Bus	0.1839	0.0886
17	Taxi	0.2036	0.0847
18	Taxi	0.2094	0.0836
		Travel time	**1.6742**
		Average Travel time	**0.0930**

Table C-3: Travel time of Small cars on middle lane

	Middle lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
1	Car	0	0.0247
2	Car	0.0016	0.0242
3	Car	0.0027	0.0242
4	Car	0.0033	0.0244
5	Car	0.0038	0.0246
6	Car	0.0044	0.0248
7	Car	0.008	0.0261
8	Car	0.0086	0.0278
9	Car	0.0094	0.0283
10	Car	0.0119	0.0289
11	Car	0.0125	0.0294
12	Car	0.013	0.0303
13	Car	0.0138	0.0309
14	Car	0.015	0.0302
15	Car	0.0158	0.0306
16	Car	0.0164	0.0311
17	Car	0.0168	0.032
18	Car	0.0178	0.0347
19	Car	0.0186	0.0361
20	Car	0.0203	0.0366
21	Car	0.0214	0.0372
22	Car	0.0242	0.0369
23	Car	0.0253	0.0369
24	Car	0.028	0.0381

Table C-3: Travel time of Small cars on middle lane (cont'd)

	Middle lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
25	Car	0.077	0.0397
26	Car	0.0306	0.0397
27	Car	0.0311	0.0408
28	Car	0.0322	0.0414
29	Car	0.0405	0.0373
30	Car	0.0416	0.037
31	Car	0.0486	0.0347
32	Car	0.0533	0.0347
33	Car	0.0547	0.0347
34	Car	0.0553	0.0349
35	Car	0.0561	0.0353
36	Car	0.0569	0.0358
37	Car	0.0575	0.0361
38	Car	0.058	0.0372
39	Car	0.0622	0.0375
40	Car	0.0627	0.0378
41	Car	0.0638	0.0384
42	Car	0.0653	0.0383
43	Car	0.0684	0.0383
44	Car	0.0697	0.0383
45	Car	0.0731	0.0374
46	Car	0.0742	0.0385
47	Car	0.0797	0.045
48	Car	0.0808	0.045
49	Car	0.0819	0.0456
50	Car	0.0936	0.0472

Table C-3: Travel time of small cars on middle lane (cont'd)

	Middle lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
50	Car	0.0936	0.0472
51	Car	0.0949	0.047
52	Car	0.0977	0.0464
53	Car	0.0991	0.0467
54	Car	0.1022	0.0455
55	Car	0.1053	0.0463
56	Car	0.1188	0.0431
57	Car	0.1196	0.0437
58	Car	0.1272	0.0431
59	Car	0.1279	0.0435
60	Car	0.1285	0.0437
61	Car	0.1296	0.0443
62	Car	0.1305	0.0445
63	Car	0.1313	0.0448
64	Car	0.1333	0.0453
65	Car	0.1427	0.0406
66	Car	0.1452	0.04
67	Car	0.148	0.0392
68	Car	0.1488	0.0392
69	Car	0.1497	0.0394
70	Car	0.1503	0.0405
71	Car	0.1511	0.0411
72	Car	0.1519	0.0417
73	Car	0.1602	0.0389
74	Car	0.1664	0.0363
75	Car	0.1686	0.0361

Table C-3: Travel time of small cars on middle lane (cont'd)

	Middle lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
76	Car	0.1697	0.0358
77	Car	0.1703	0.0358
78	Car	0.1756	0.0349
79	Car	0.1767	0.0349
80	Car	0.1778	0.0352
81	Car	0.1789	0.0347
82	Car	0.1806	0.0349
83	Car	0.1847	0.0355
84	Car	0.1855	0.0352
85	Car	0.1875	0.0343
86	Car	0.1883	0.0346
87	Car	0.1964	0.031
88	Car	0.2011	0.0302
89	Car	0.2019	0.031
90	Car	0.2038	0.0331
91	Car	0.2061	0.0327
92	Car	0.2067	0.0332
93	Car	0.2069	0.0342
94	Car	0.2075	0.0355
95	Car	0.2083	0.0358
96	Car	0.2116	0.0358
97	Car	0.2127	0.0364
98	Car	0.2133	0.0392
99	Car	0.2155	0.0398
		Travel Time	**3.6302**
		Average Travel Time	**0.0366**

Table C-4: Travel time of HOVs on middle lane

	Middle lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
1	Taxi	0	0.0328
2	Taxi	0.0033	0.0361
3	Taxi	0.0189	0.0453
4	Taxi	0.0217	0.0464
5	Taxi	0.0441	0.0411
6	Taxi	0.0452	0.0417
7	Taxi	0.0592	0.0461
8	Taxi	0.0675	0.0539
9	Taxi	0.0698	0.0541
10	Taxi	0.0771	0.0526
11	Taxi	0.0789	0.053
12	Taxi	0.0805	0.0528
13	Taxi	0.0836	0.0533
14	Taxi	0.0891	0.0542
15	Taxi	0.0963	0.0534
16	Taxi	0.1017	0.0533
17	Taxi	0.1033	0.0533
18	Bus	0.1061	0.0539
19	Taxi	0.1135	0.0515
20	Taxi	0.1243	0.0524
21	Taxi	0.1252	0.0523
22	Taxi	0.1394	0.0469
23	Taxi	0.1455	0.0494
24	Taxi	0.148	0.0486
25	Taxi	0.1603	0.0435

Table C-4: Travel time of vehicles on middle lane (cont'd)

	Middle lane Monday (8:15 a.m. – 8:30 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
26	Bus	0.165	0.0425
27	Taxi	0.1725	0.0422
28	Bus	0.1739	0.0427
29	Taxi	0.1756	0.0427
30	Taxi	0.1763	0.0428
31	Taxi	0.1822	0.0419
32	Taxi	0.19	0.0385
33	Bus	0.1919	0.0377
34	Taxi	0.1958	0.0391
35	Taxi	0.2111	0.0466
36	Bus	0.2131	0.0469
		Travel Time	**1.6855**
		Average Travel Time	**0.0468**

Table C-5: Travel time of small cars on outer lane

	Outer Lane Tuesday (8:30 a.m. – 8:45 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
1	Car	0.013	0.0341
2	Car	0.0144	0.0356
3	Car	0.0147	0.0372
4	Car	0.0152	0.0378
5	Car	0.0158	0.0383
6	Car	0.0166	0.0389
7	Car	0.0195	0.0432
8	Car	0.0208	0.0428
9	Car	0.0295	0.0472
10	Car	0.0333	0.0439
11	Car	0.0361	0.0439
12	Car	0.0375	0.0442
13	Car	0.0388	0.044
14	Car	0.0441	0.0419
15	Car	0.0463	0.0420
16	Car	0.0480	0.0416
17	Car	0.0580	0.042
18	Car	0.0687	0.0388
19	Car	0.0707	0.0398
20	Car	0.0712	0.0418
21	Car	0.0724	0.0437
22	Car	0.0737	0.0507
23	Car	0.0746	0.0512
24	Car	0.0760	0.0515
25	Car	0.0785	0.0537

Table C-5: Travel time of small cars on outer lane (Cont'd)

	Outer Lane Tuesday (8:30 a.m. – 8:45 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
26	Car	0.079	0.0557
27	Car	0.0855	0.0536
28	Car	0.093	0.0486
29	Car	0.1	0.0447
30	Cars	0.1016	0.0442
31	Car	0.103	0.0486
32	Car	0.1044	0.0494
33	Car	0.1061	0.0497
34	Car	0.1072	0.0503
35	Car	0.1077	0.0506
36	Car	0.1111	0.0497
37	Car	0.1222	0.0545
38	Car	0.1278	0.0525
39	Car	0.1328	0.0483
40	Car	0.1333	0.05
41	Car	0.1416	0.0461
42	Car	0.1446	0.047
43	Car	0.1505	0.0422
44	Car	0.1588	0.0361
45	Car	0.1603	0.0363
46	Car	0.1616	0.0403
47	Car	0.1666	0.0434
48	Car	0.1752	0.0443
49	Car	0.1774	0.0443

Table C-5: Travel time of small cars on outer lane (Cont'd)

	Outer Lane Tuesday (8:30 a.m. – 8:45 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
50	Car	0.1802	0.0432
51	Car	0.1821	0.0435
52	Car	0.1874	0.0412
53	Car	0.1933	0.0408
54	Car	0.2036	0.0341
55	Car	0.2067	0.0354
56	Car	0.2077	0.0356
57	Car	0.2103	0.0346
58	Car	0.2111	0.0361
59	Car	0.2116	0.0375
		Travel Time	2.5822
		Average Travel Time	0.04376

Table C-6: Travel time of HOVs on outer lane

	Outer Lane Tuesday (8:30 a.m. – 8:45 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
1	Taxi	0	0.0611
2	Taxi	0.0033	0.0611
3	Taxi	0.0049	0.0606
4	Bus	0.0085	0.066
5	Taxi	0.0165	0.0613
6	Taxi	0.0274	0.0603
7	Taxi	0.0316	0.0625
8	Taxi	0.0326	0.0634
9	Taxi	0.041	0.0609
10	Taxi	0.0421	0.062
11	Taxi	0.0435	0.0626
12	Taxi	0.0512	0.0588
13	Taxi	0.0546	0.069
14	Taxi	0.0581	0.0707
15	Taxi	0.0594	0.0711
16	Taxi	0.0612	0.0752
17	Taxi	0.062	0.0685
18	Taxi	0.0629	0.0707
19	Taxi	0.0634	0.0735
20	Taxi	0.0732	0.0668
21	Taxi	0.076	0.0673
22	Taxi	0.0946	0.0673
23	Taxi	0.0966	0.0661
24	Taxi	0.0971	0.0665

Table C-6: Travel time of HOVS on outer lane (Cont'd)

	Outer Lane Tuesday (8:30 a.m. – 8:45 a.m.)		
Number	**Car type**	**Headway (hr.)**	**Travel time (hr.)**
25	Taxi	0.1013	0.0631
26	Bus	0.1022	0.0717
27	Taxi	0.103	0.0726
28	Taxi	0.1047	0.0739
29	Bus	0.116	0.0686
30	Taxi	0.1173	0.0687
31	Bus	0.1246	0.0642
32	Taxi	0.146	0.0604
33	Taxi	0.1487	0.0632
34	Bus	0.1501	0.0637
35	Taxi	0.1514	0.0644
36	Bus	0.1534	0.0644
37	Taxi	0.1603	0.0619
38	Taxi	0.1623	0.0627
39	Taxi	0.1651	0.0622
40	Taxi	0.1704	0.0591
41	Taxi	0.1715	0.0602
42	Taxi	0.179	0.057
43	Taxi	0.1868	0.0534
		Total travel time	**2.7887**
		Average travel time	**0.0648**