STUDY OF THE PERFORMANCE OF PASSING AND CLIMBING LANES ALONG COLOMBO – RATHNAPURA – WELLAWAYA – BATTICOLO ROAD

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Degree of Master of Science in Transportation

Department of Civil Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

Study of the Performance of Passing and Climbing Lanes Along Colombo – Rathnapura – Wellawaya – Batticolo Road

Due to increase of population and rapid economic growth, percentage of heavy and recreational vehicles in the traffic stream from Colombo Capital to Central hills have increased causing severe traffic congestions. Specially all essential supplying services including fuel, food, export goods transport using major highways. Applying climbing lane concept on two-lane highways can be a good recommendation to reduce prevailing extreme conditions. “A climbing lane is, in effect, a passing lane added on an upgrade to allow traffic to pass heavy vehicles whose speeds are reduced”. However, application of Passing Climbing Lanes (PCL) are not a common practice in Sri Lanka. Most of steep upgrades on the major trans mountain highways do not have climbing lanes that cause traffic congestion on major highways. Due to the increasing vehicular traffic along the route, there exists an ongoing construction of Passing climbing lane on Colombo- Rathnapura-Wellawaya- Batticolo (CRWB) road near to Rathnapura. This study evaluates the Impact of Passing and Climbing lane on traffic flow on the particular section at CRWB road considering both travel time and delay time using the existing available data from RDA and new traffic survey data. The collected data at particular location before the construction of PCL and after is expected to show the importance of having PCLs at essential places along CRWB. Further, the impact of selected PCL has been analyzed for various traffic volume by a simulation model which was developed for this study. PCL is low cost improvement method rather than replacing extra lane or providing bypass lane, hence study discusses the economic advantages also.

Key Words: Passing Climbing lanes, Two-lane highways, Performance of climbing lane

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LIST OF ABBREVIATIONS

Abbreviation	Description
CRWB	Colombo- Rathnapura- Wellawaya- Batticolo highway
PCL	Passing Climbing Lane
HCM	Highway Capacity Manual
LOS	Level of Service
DHV	Design Hourly Volume
RDA	Road Development Authority
USA	United States of America
ASSHTO	American Association of state Highway Transport officials
TRB	Transport Research Board
DHV	Design hourly volume
ATS	Average Travel Speed
PTSF	Percent Time Spent following
PFFS	Percent Free Flow Speed
PCU	Passenger Car Unit
ITS	Intelligent Transport System

1 INTRODUCTION

1.1 Background of the Study

Slow moving vehicles on roads, have lack of opportunities to overtake due to shorter sight distance and heavy traffic volumes on opposite sides in dense platoons create considerable traffic congestion and increase accidents on roads. Drivers are forced to wait at a longer time period following other vehicles. Then they were allowed to overtake front vehicle using the dedicated lane to the opposite travel direction when there is no opposite side traffic. This is a risk to the drivers based on their driving habits and un justiciable overtaking. This situation is getting worst in many developing countries like Sri Lanka due to the presence of overloaded trucks and buses with low power to weight ratios. Due to this, introducing climbing lane concept on two-lane highways will be extremely beneficial rather than constructing four lane highways. (transport research board, 2010). Further, climbing lanes facilitates vehicles to move up the gradient to overtake efficiently and safely.

This study aims to evaluate the operational performance after implementing of climbing lanes on two-lane highways as a solution of increasing traffic problems in Sri Lankan roads. Concept of climbing lane system is a not a common practice in Sri Lanka though it has a long history in other countries like USA, Canada etc. (McGui et al, 2005). Sri Lankan road network consist of few climbing lanes at locations where Dambulla, Pathulpana...etc. This study only focuses on class A two-lane highway, Colombo Rathnapura Wellawaya Batticolo Highway. With road segment length that leads for having 30 - 35 kmph speed decrease on upgrade ranging from 6% -10%, which connects to a flat terrain.

1.2 Research Problem

Climbing lanes are new for roadway section in Sri Lanka. There exist few climbing lanes in Sri Lankan road network. The Sri Lankan roadway network consist of more sections with higher gradient, due to mountain region in central part of the country. With the increasing traffic the network should be upgrade to cater the increasing traffic. There are many available sections that requires to improve by adding climbing lanes to improve roadway capacity. But lack of studies and data with Sri Lankan conditions creates problems while planning and designing climbing lane section in two-lane highways in Sri Lanka. Therefore, by this study it provides some performance evaluation recommendations for planning of climbing lanes in future in Sri Lankan two-way highway network.

1.3 Justification of the Problem

Colombo- Rathnapura-Wellawaya- Batticolo (CRWB) highway also named as A4 highway considered as the longest highway in Sri Lanka with the length of 430 km. It connects western suburbs with eastern part of the country where you may meet major destinations like Awissawella, Kuruwita, Rathnapura, Pelmadulla, Balangoda, Beragala, Wellawaya, Badulla, Monaragala, Siyambalanduwa, Lahugala, Potuvil, Kalmunai and Batticolo towns. All the essential supplies and export products are transporting along this highway from eastern region to Colombo port. After the end of 30-year ethnic war, significant changes occur in tourism industry while creating new tourism destinations in eastern coast and new travel routes.-Therefore, Observations of traffic conditions along the CRWB Highway during past decade shows that number of trucks, other heavy vehicles and recreational vehicles that travels increased significantly creating decreasing level of service and safety. The present level of service on CRWB highway is at D condition with the average speed of 40-45 mph per hour at many sections. Therefore, upgrading the CRWB highway to 4 lanes is a must and Road Development Authority also identified this as their one of future priority projects. With the lack of funding availability, implementation of this project gets delayed for many years. As an alternative solution, addition of climbing lane concept could be adopted at suitable locations as a cost-effective method. There exists one climbing lane alone CRBW highway near Rathnapura is a pilot project for this concept.

1.4 Research Aims and Objectives

Objective of this research was to estimate the operational performance of implemented climbing lane in a two-lane highway (CRBW), for the purpose of diverting Heavy Occupancy Vehicles (HOVs). In this study, the evaluation has been done using one of the most popular microscopic traffic simulation software called

VISSIM for two different scenarios for two different models. Average travel speed and total travel time delay has been used for the evaluation of operational performance.

1.5 Limitation of the Study

Climbing lanes are two types, pocket type and overtaking type, (Choi, Suh, & Yeo, 2017) in pocket type climbing lanes the additional lane is located at most outer lane of the road section. The purpose of the axillary lane is to divert slow moving vehicles in to that lane in order to not to high speed vehicles.

The overtaking type of climbing lane is that there is an additional lane installing at the inner side of the road section (close to the road center) for high speed vehicles. In this case at the diverging location (entrance) heavy vehicles do not want to change the lane and these vehicles eventually flow to the outer side lane. Though half of Sri Lankan road network go through along mountain and hilly areas with many incline sections, few climbing lanes were installed in total road network. Among those climbing lanes the climbing lane in CRWB highway location near a town (Rathnapura) where there are lot traffic using climbing lane section compared to the other locations. This climbing lane can be categorized as pocket type climbing lane considering its geometry and operational practice. The fore this study limits to study the pocket type climbing lane at a certain location in a two-lane highway area. The simulation model has been developed using the road characteristics at the location of the so-called climbing lane in CRWB highway and the evaluation results valid for the other places where the same roadway conditions exists.

Further evaluation of climbing lane performance has a vast area based on the literature. As per the literature evaluation can done considering operational efficiency, economical beneficiaries, safety enhancement, roadway conditions etc. This study only limits to evaluate the operational performance based on the delay time and average travel speed of the traffic along the section.

1.6 Organization of the Research

This thesis consists of five chapters. First chapter presents the background of the research, research problem and the aim and the objectives of the study. The second chapter includes literature survey including performance of climbing lanes, factors affecting climbing lanes, efficiency of climbing lanes with evidences based on studies done in other countries etc. The third chapter describes the methodology of this research. Chapter 4 Results of simulation model and Discussion. Chapter 5 includes Conclusion of the thesis with recommendations for future applications.

2 LITERATURE REVIEW

2.1 Two - Lane Highway

Two-lane highways consist of two-lanes with one lane in each direction and majority of the highways are undivided. Therefore, it is mandatory to use other lane to overtake slow moving vehicles. At this situation two-lane highway must be provided with sufficient sight distance or no passing zones (Manual, 2000).

Limited passing distance always creates platooning on the road. To overcome this, effective methods such as turnouts, passing lanes at given intervals in each direction and climbing lanes on upgrades are available, (Dassanayake, 2006). In this research, we discuss about the effects of climbing lanes. (Manual, 2000)

Climbing lanes facilitates other vehicles to pass slow moving vehicles by adding a shorter length lane to the right side of upgrades. It is essential to have climbing lanes where slow-moving vehicles like trucks, heavy agricultural vehicles etc. effect the total traffic flow and its speed as rear faster moving vehicles have no or less opportunity to overtake. In this situation faster moving vehicles must stay and move closely to the slower ones until they have a chance to pass where it creates platooning on roads. (ASSHTO,2011)

2.2 Definitions of Climbing Lanes

As per the definition given by HCM, a climbing lane is, in effect, a passing lane added on an upgrade to allow traffic to pass heavy vehicles whose speeds are reduced. Generally, a lane is added to the right, and all slow-moving vehicles should move to this lane, allowing faster vehicles to pass in the normal lane. (HCM, 2010).

Climbing lanes increase the cross section of a highway (increasing number of lanes) at certain short travel lengths. This additional lane segment used by slower moving vehicles to allow fast moving vehicles while staying in the normal lane. But in regular passing lane fast moving vehicles move to the additional lane to overtake slow moving vehicles, which stay in normal lane (TRB, 2010).

(A, J, & I, 1981) A multiphase study of heavy vehicle flow on downgrades that considered with geometric and flow warrants for inclusion of truck climbing lanes on two-lane rural highways. Among the two criterions they have concerned, introduction on climbing lanes for both upgrade and down grade directions were based on the LOS concept. Through the study they have suggested set of volume graphs for LOS criterion. They have stated that there is a strong interrelationship between the percentage of trucks, the rate and length of grades and the service volume for LOS. Another factor they have studied the speed reduction or increment in climbing lanes. (Dassanayake, 2006)

(Mendoza & Mayoral) conducted a study in 2000 in Mexico to study economic feasibility of applying climbing lanes on two-lane highways. They also evaluated the levels of service before and after implementing these facilities using a computer model TRARR. The collected data of certain locations where climbing lanes presence had been evaluated based on HCM criteria for LOS of specific grades on two-lane highways in Mexico. They emphasized that applying LOS criteria published by HCM should be upgrade due to the driver behaviors and characteristics of Mexican roads and published the values of updated Average Travel Speeds (ATS) for Mexican roads. Figure 2.1. (AASHTO, 2011)

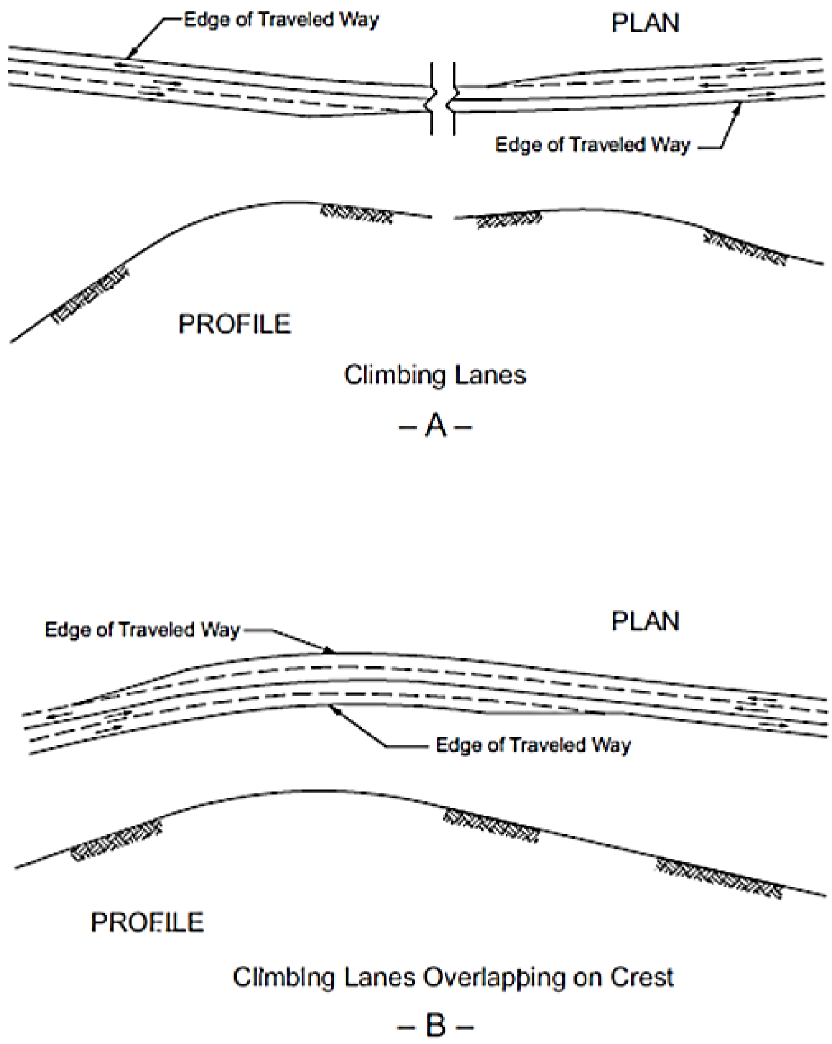

Figure 2.1 Climbing lane in Two-Lane Highway (AASHTO, 2011)

In prevailing conditions, many countries practice either method out of two alternatives that exists considering climbing lanes. First practice is guidelines given by AASHTO, where it recommends applying climbing lanes when critical length of grade is exceeding the traffic volume, percentage of heavy trucks presence on the road are justifying the investment. But when the truck speed is less than 15 km/h, AASHTO does not recommends climbing lanes emphasizing delays caused by truck in this case are within reasonable limits. Further it recommends when critical length of grade is exceeded, climbing lanes should apply considering highway capacity standpoint. It is considering Design Hourly Volume (DHV) should not more than design capacity on an individual grade by more than 20%.

In the second alternative introduced by Stimpson and Glennon reduced AASHTO criterion to 10 km/h and climbing lanes are justified when DHV equals or exceeds the design capacity of grade.

2.3 Performance Measurement of Two-lane Highways in Sri Lanka

When evaluating the operational performance of two-lane highways, the Highway Capacity Manual (HCM) declares the concept called Level of Service (LOS) analysis which consist of three of parameters. The Average Travel Speed (ATS), the Percent Time Spent Following (PTSF), and Percent Free Flow Speed (PFFS) (Manual, 2000)

Further, HCM Manual 2010, (Board, 2010) categorize the two-lane highways in to 2 classes, class 1 – high speed roads, arterials, primary highways that afford mobility, ATS, PTSF defines the LOS.

Class 2 highways- access routes to class 1 facilitates or serve for shorter trips, do not expect to travel at high speeds, PTSF determines the LOS.

In Sri Lanka, there are no existing published guideline for implementation and performance analysis for climbing lanes on two-lane highways. Therefore, we considered two measurements called Total delay time and Average travel speed for operational performance checking of climbing lanes in two-lane highways.

2.4 AASHTO Guideline for Climbing Lane Implementation

HCM (Manual, 2000) states that according The American Association of State Highway and Transportation Officials (AASHTO) climbing lanes are warranted in two-lane undivided highway under following conditions.

- The flow rate on the upgrade direction exceeds 200Veh/h
- The percentage of Heavy occupancy vehicles on the upgrade direction exceeds 20 Trucks/h
- Any of following conditions can consider too.
    - Reduction of speed of a truck 15 km/h or more for the usual 120 kg/kW;

- The LOS considered to be in grading E and F for the upgrade section without a climbing lane;
- No presence of a climbing lane, the LOS is two or more levels lower for the upgrade section than on the approaching section to the upgrade section.

Table 2.1 Climbing lane design consideration (Source: AASTHTO,2011 and State DOTs)

Climbing lane design	AASHTO	State of DOTs
Start-up Location	Where trucks speeds are not tolerable any more (critical length)	Per AASHTO
End Location	Beyond crest, where truck reaches a speed up to 40mph or only varies up to 10mph to surrounding traffic	Per AASHTO
Width	12ft	Per AASHTO
Entry Taper length	At least 300ft, with 25:1 ratio	150-500ft with 25:1 ratio
Exit Taper length	At least 6000ft given 50:1 ratio	Minimum of 200ft with varying ratios depending on design speed (50:1,60:1,70:1)
Shoulder width	Maintained for whole segment	Maintained, but may be reduced to 4ft.If climbing lane width is 11ft, shoulder width mist be 5ft wide.

2.5 Warrants on Climbing Lane Designs in Sri Lanka

Table 2.2 Geometric design standard of road development authority in Sri Lanka

Grade %	Critical length (m)
3	480
4	330
5	250
6	200
7	170
8	150
9	140
10	135
12	120

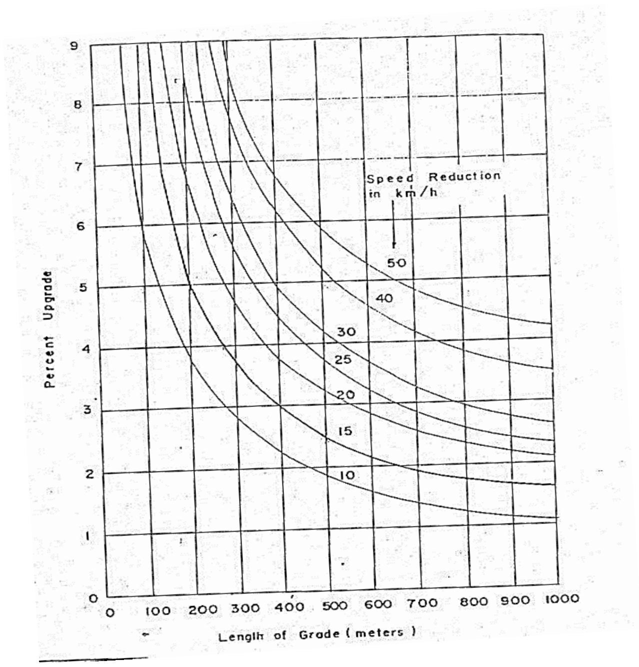

Figure 2.2 Critical lengths of gradient (for truck -180kg/kw, & enter speed 90kmph) (source: RDA manual for design climbing lanes)

3 RESEARCH METHODOLOGY

3.1 Introduction

Existing climbing lane in CRWB A4 Highway in Pathulpana. This location situated 7 km away from the Rathnapura town and after passing the Thirawanaketiya Junction (Proposed Ruwanpura expressway exists). The road was designed for average speed of 50 kmph for light weight vehicles and 40 kmph for heavy vehicles. The designed flow rate of CRWB highway is 1200 PCU/hr.

Figure 3.1 Location map

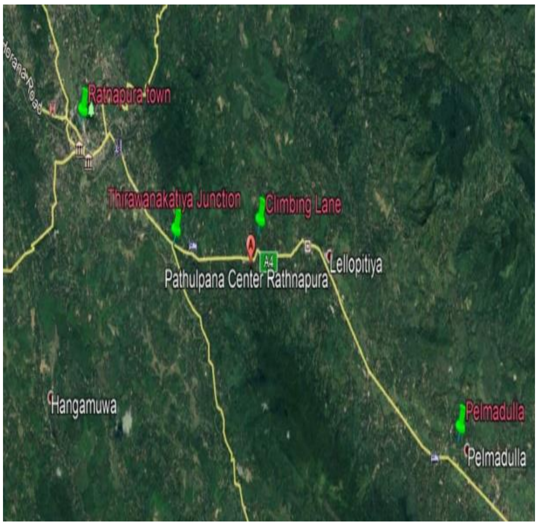

Figure 3.2 Site map

:

3.2 Geometry of the Experimental Section

The roadway made of two-lanes of 3.75m with increasing soft shoulders of 1m to the both right and left. The climbing lane has been installed to the road way section with variant gradients and the variant Vertical Curve Lengths (VCL) along the chainage, as per the geometric design is shown in table 3.1. therefore, there is an average of 6% gradient along 0.3km length of the existing climbing lane. Figure 3.3 showed the plan view and profile of the two-lane highway with added climbing lane.

Table 3.1 Vertical curvature and gradient details of the climbing lane

Chainage	Gradient / %	VCL / m
0 – 0+010	4.53	-
0+010 – 0+085	-	75
0+085 – 0+140	9.04	-
0+140 -0+150	-	10
0+150 – 0+180	6.12	-
0+180 – 0+280	-	100
0+280 -0+290	7.49	-
0+290 – 0+315	-	25
0+315 – 0+325	5.55	-
0+325 – 0+375	-	50
0+375 – 0+391	6.39	-

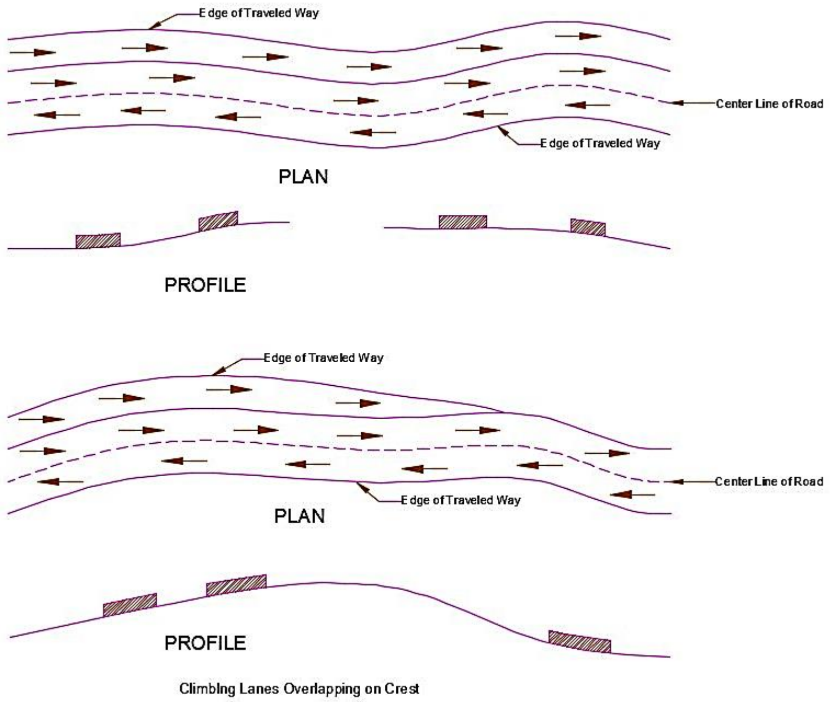

Figure 3.3 Plan and profile view of the existing climbing lane along CRWB highway

3.3 Location Photos

Figure 3.4 Climbing lane in CRWB highway

Figure 3.5 Climbing lane upstream point

3.4 Traffic Condition in the Climbing Lane

The established climbing lane functions as a pocket type climbing lane that heavy occupancy vehicle divert in to the climbing lane section letting other vehicles to travel on the two-lane section. At the end of the climbing lane HOVs will merge with normal traffic flow. As per the recorded data, there is an average 578 veh/hr during peak hour at the climbing lane roadway section daily. The HOVs percentage is about 10% from the total traffic flow.

3.5 Data Collection Procedure

An operational evaluation has been for the location by using traffic performance data collected in the field. Manual data count has been done by numerators. Two manual observers at two locations (diverging point and merging point of the climbing lane) recorded traffic data and 15-minute data for one hour and for day time (12 hours) daily were collected for a whole week. The considered week is an ordinary week without any special traffic operation plans weren't considered.

Classified traffic data has been arranged as per following format for climbing lane, normal lane and downwards lane.

Passing lane CRWB

Classified Flow

Location : O

Movement : PG

Date : Thursday 27 Sep 2018 From : P To : G

	0.5	0.8	1	1.6	1.7	1.8	1.5	1.6	1.7	2.8	2.8	2.8	2.8	2.8	3.4		
Time	Motor Bike	3-Wheeler	Car/ Jeep	Pasenger Van	Medium Bus	Large Bus	Light Goods Vehicle	Lorry	Large Lorry	3 - Axle Rigid	3 - Axle Art.	4 - Axle Art.	5 - Axle Art.	6 - Axle Art.	Farm Vehicle	Total	PCU Tota
06.00 - 06.15																	
06.15 - 06.30																	
06.30 - 06.45																	
06.45 - 07.00																	
07.00 - 07.15																	
07.15 - 07.30																	
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09.00 - 09.15																	
09.15 - 09.30																	

Figure 3.6 Sample data collection sheet

3.6 Simulation

Due to the difficulty of collecting sufficient data for emphatical modeling that requiring a large no of variables, this study uses the simulation approach to evaluate the operational efficiency of the climbing lane. Simulation approach has an advantage of evaluating many possible scenarios within a reasonable time fame and a budget. It also can provide systematic and comprehensive analysis.

3.7 Simulation Model Selection

In general simulation models can be categorized as macroscopic and microscopic models. The macroscopic approach considered total traffic flow while microscopic models considers mobility of each individual vehicle. Microsimulation models are essential to predetermine the behavior of traffic and all other road users as a result of future improvements or additions to the Road Network. Microsimulation traffic models are used by planners to generate different scenarios, optimize control, and predict network behavior at the operational level before taking most important decisions relevant to road infrastructure development. These models are considered as tools for decision making. Further, traffic microsimulation will lead to experiment new techniques or control systems without knowing the level of disruption to people/traffic in a real network before implementation and this process assist to remove unnecessary issues and waste of money when various people /organizations try to implement non-feasible projects (A, J, & I, 1981). There are different types of microscopic simulation models exists. Ex: FREFLO (Hou, Meng, Huo, Cheng, & Leng, 2019), CORSIM, VISSIM, OFFA (Choi, Suh, & Yeo, 2017). for this study it was used VISSIM due to its capability of modeling passenger vehicles and HOVs for arterial roads. And capability of analyze wide range of traffic, geometric and control variables and generate measures like travel time, delay time, speed, density etc.

3.7.1 Advantages of Microsimulation Modeling (VISSIM)

Micro simulation modeling is a powerful tool. It can greatly enhance decision making and more effectively analyze. Then it evaluates proposed improvements and compare alternatives. Following mentioned key advantages of micro simulation modeling

- Ability to evaluate and isolate differences by mode and by lane. (Bus Lane)
- Ability to model variations in volume and congestion over the peak hour.
- Ability of evaluate system impacts and influences.
- Ability to model the benefits of ITS and technology improvements that may target specific classes of vehicles or conditions.
- Ability to model influences of geometric changes.
- Simulation is cheaper than many forms of field experimentation and analytical modelling, in terms of time, resources and cost.
- Micro Simulation models are "transparent," in the sense that anyone who wishes to know how they work can see through the model.

3.7.2 Climbing lane section for model simulation

for the simulation model following road characteristics are used. Length of the climbing lane is 0.3 km and slope is 6% and considered the two-lane highway section as shown in figure 3.7.

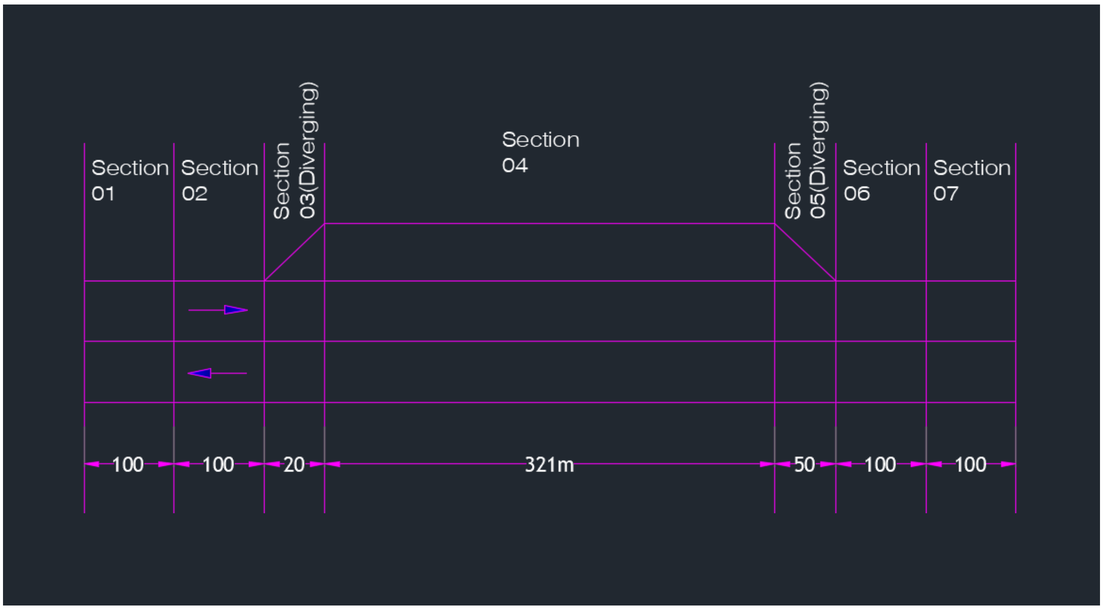

Figure 3.7 climbing lane section for model simulation

3.7.3 Parameter values on modeling

The parameter values included for the model as following table 3.2. the average flow speed of vehicles depends on the vehicle type categorized here as normal vehicles and heavy occupancy vehicles. A field video test was conducted to observe these parameters from real data. But though a field video was observed, it was difficult to make quantitative evaluation. Because only free flow data could observe due to no divers traffic flows. But for the climbing lane performance evaluation various traffic inflows should be used. Hence in simulation runs we used various traffic inflows with different HOVs ratios. This simulation runs did for both climbing lane presence and no climbing lane presence scenarios. Each traffic demand with various input flows and HOVs ratios were simulated for 1 hour with 15 minutes intervals.

Table 3.2 Parameters and values used for model simulation

parameter	Normal vehicle Heavy occupancy vehicle
Traffic volume -	578 veh/hr
Free flow Speed -	For normal vehicle 30 km/hr Heavy occupancy vehicle 20 km/hr
Length of CL	391m
Geometry	6%
Parameters for Scenario simulation	
Scenarios	With climbing lane and without climbing lane scenarios
Heavy vehicle percentage	9.1% ,12.3%, 15.3%, 17.9%, 20.5%, 22.9%, 2.5.2%
Total traffic volume	578,598, 618,638, 658, 678 Veh/hr
Climbing lane length	391,420,464,524 m

3.7.4 Simulation scenarios.

The traffic data were run by creating different models in following scenarios.

Scenario 1: two-way highway section was modeled with including the considered climbing lane section to the most outer lane side. The model was simulated for changing HOVs ratios and for different traffic inflow rates

Scenario 2: two-way highway section was modeled with including the considered without climbing lane section. The model was simulated for changing HOVs ratios and for different traffic inflow rates.

Model 1: Evaluate operational performance with and without climbing lane scenarios for different traffic characteristics (For different HOVs ratios and for different traffic inflow rates)

To evaluate the operational performance of two-lane undivided highway with and without climbing lane and simulate 1 hr by using VISSIM software, delay time and travel time is simulated. These generated data were tabulated and compared, to examine the effect of changing the heavy vehicle percentage on the performance of climbing lanes, increase the heavy vehicle percentage. In initial stage there was 9.1 % heavy vehicle contribution to the climbing lane. During the simulation, the effect to the climbing lane was observed by increasing the heavy vehicle contribution by 5% at a time considering HOV ratios, 9.1% ,12.3%, 15.3%, 17.9%, 20.5%, 22.9%, 2.5.2%. Further, to examine the effect of changing the total traffic volume on the performance of climbing lanes, increase the total traffic volume. Present traffic volume is 578. Due to urbanization, there is a potential to increase this figure in the future. As this section lay through on highly urban area and it also lies on major province the future demand may increase and hence the effect of climbing lane should be considered. Therefore, the traffic flow was increased by 20 for each sub scenario and simulated for 1hour in VISSIM software, as 578 veh/hour, 598 veh/hr, 618 veh/hr, 658 veh/hr, 678 veh hr,

Model 2: Evaluate operational performance of climbing lane scenario for different geometric characteristics (For fixed HOVs ratios and for different traffic inflow rates)

A simulation was done to check the efficiency of designed climbing lane length as a separate model. This model was planned to understand that whether it should increase the climbing lane length for better performance or not. For the simulation run, the present average daily heavy occupancy vehicle (trucks, buses etc) ratio is considered to be 10% as observed from the video. For different traffic flow rates and the climbing lane lengths were obtained from the model. When the current traffic volume increase, the climbing lane is unable to function its full capacity due to saturation of vehicle. In this situation increasing the climbing lane length is essential. Hence simulations were conducted for one hour (using VISSIM (software) by increasing the traffic volume by intervals of 20 and by increasing the climbing lane length increase by 10%.

4 RESULTS AND DISCUSSION

4.1 Introduction

The total delay time is one of the mostly used parameter for finding the operational performance in road way sections. For this study we considered this parameter because it was directly observed from the VIISIM simulation

Another considered parameter considered for operational efficiency was Average travel speed. For A vehicle, total travel time taken to complete the considered section with climbing lane scenario is less compared to the without scenario. Average travel speed was calculated using following equation.

ATS = Effective road length /Total Travel time

4.2 Total Delay Time

This study is to evaluate the operational efficiency of the climbing lane in CRWB road, total delay is a widely used index for operational performance. As per the evaluation results by VISSIM. Total delay results for a vehicle with the presence of HOVs on the road, for a climbing lane section has been compared to the no climbing lane scenario were evaluated

4.2.1 Total delay time for different heavy occupancy vehicle percentage

Total delay time can be considered for two situations. At first for a fixed traffic flow rate the variation of total delay time for various heavy occupancy vehicle percentages can be observed. At this situation the fixed traffic flow was considered of 578 veh/hr Table 4.1 shows total delay both cases with climbing lane and without climbing lane while increasing the heavy vehicle percentage and the relevant column chart for Total delay time vs heavy occupancy vehicle percentage shown in figure 4.1

Table 4.1 Total delay time for climbing lane with and without scenarios for different heavy occupancy vehicle percentages

Heavy vehicle percentage	**With climbing lane**	**Without climbing lane**
	Total delay (sec)	Total delay (sec)
9.1%	44	60
12.3%	48	64
15.2%	45	66
17.9%	53	67
20.5%	53	68
22.9%	55	68
25.2%	55	68

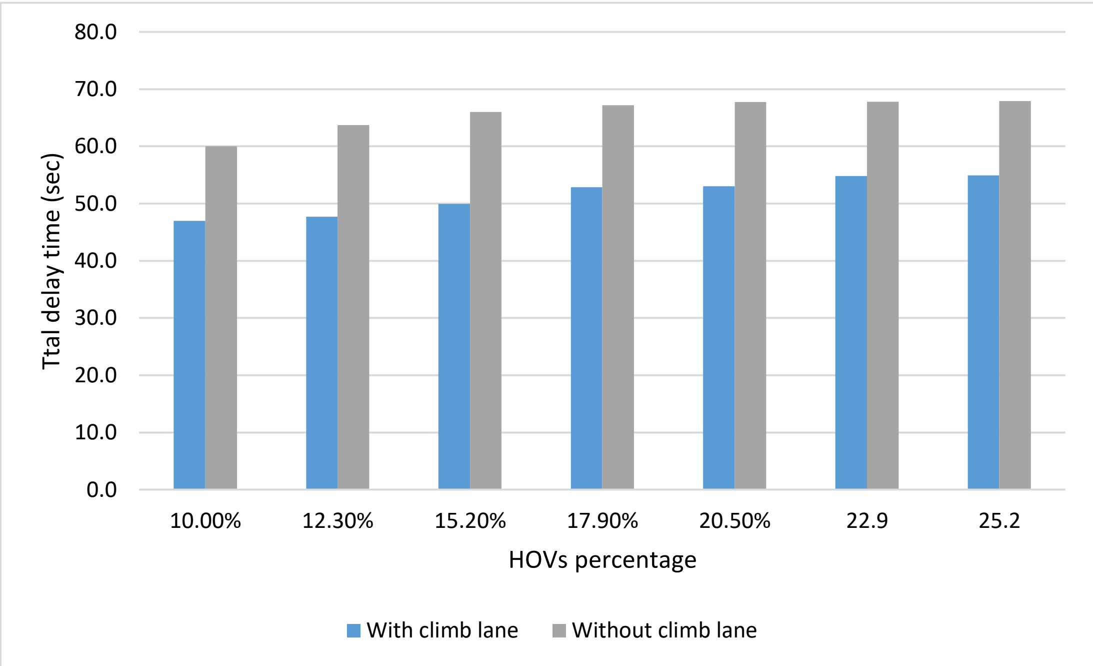

Figure 4.1 Total delay time for climbing lane with and without scenarios Vs different heavy occupancy vehicle percentages

4.2.2 Total delay time for different flow rates

Total delay time can be model for different flow rates with fixed heavy vehicle percentage (10%). The model results for the total delay time for various flow rates as shown in table 4.2 and the relevant column chart shows in figure 4.2.

Table 4.2 Total delay time for climbing lane with and without scenarios for different flow rates

Traffic flow rates (veh/hr)	**With climbing lane**	**Without climbing lane**
	Total delay time (sec)	Total delay time (sec)
578	44	60
598	50	64
618	53	67
638	53	70
658	55	72
678	56	73

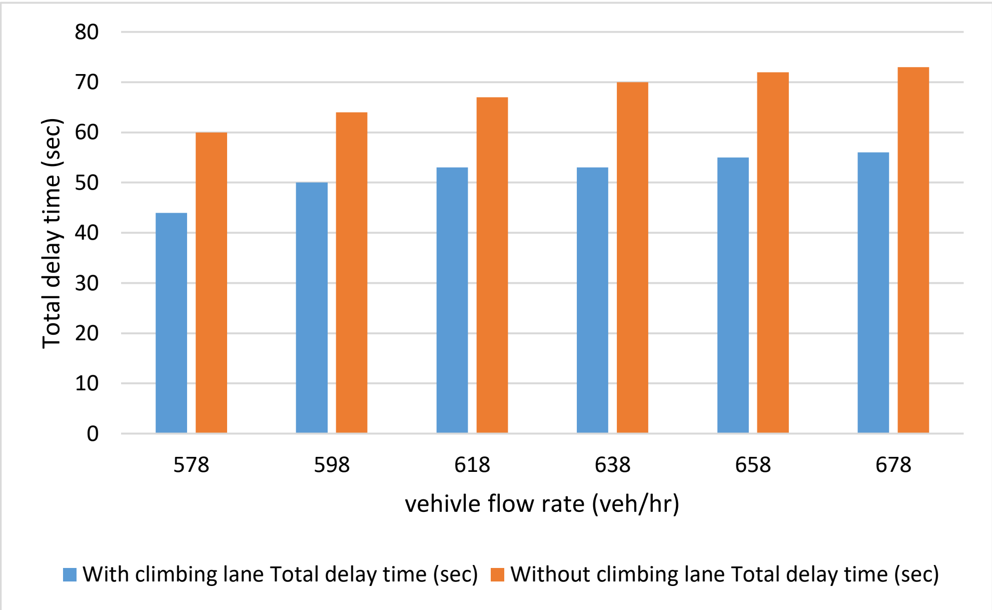

Figure 4.2 Total delay time for climbing lane with and without scenarios Vs different flow rate

4.3 Average Travel Speed

Average travel speed can be considered for two situations .at first for a fixed traffic flow rate (578 veh/hr) the variation of average travel speed for various heavy occupancy vehicle percentages can be calculated.

4.4 Average travel speed for different Heavy occupancy vehicle percentages

Table 4.3 shows average travel speed for both cases with climbing lane and without climbing lane while increasing the heavy vehicle percentage and the relevant column chart for ATS vs heavy occupancy vehicle percentage shown in figure 4.3.

Table 4.3 Average travel speed for different Heavy vehicle percentages with and without climbing lane

Heavy vehicle percentage	**With climbing lane**	**Without climbing lane**
	ATS (m/s)	ATS (m/S)
9.1%	2.4	2.26
12.3%	2.39	2.19
15.2%	2.32	2.12
17.9%	2.24	2.07
20.5%	2.19	2.02
22.9%	2.11	1.99
25.2%	2.11	1.97

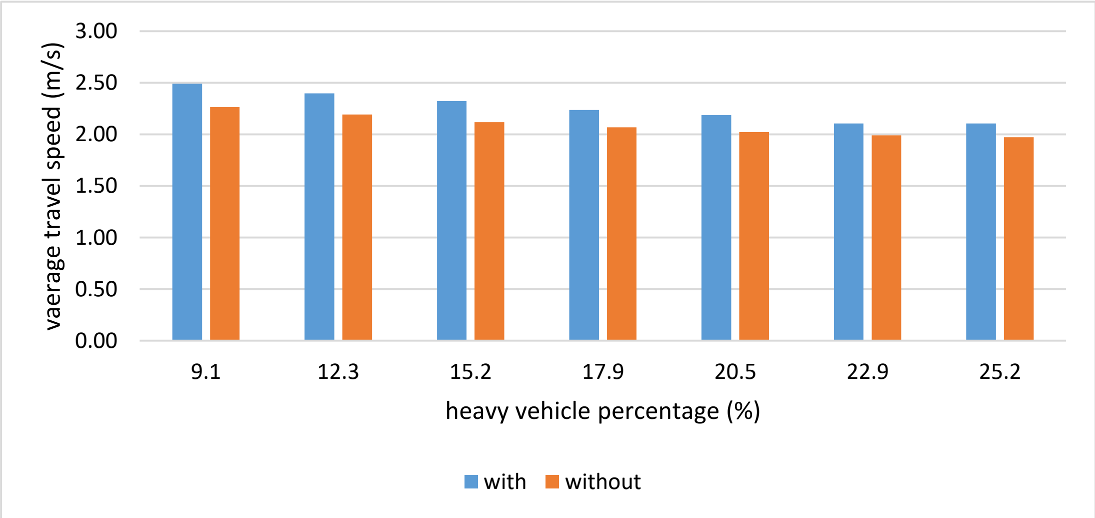

Figure 4.3 Average travel speed vs heavy vehicle percentages

According to the figure 4.5, travel time increases when the heavy vehicle percentage increases.

4.4.1 Average travel speed for different traffic flow rates

for a fixed heavy occupancy vehicle percentage (10%) the variation of average travel speed for various flow rates can be calculated. Table 4.4 shows Average travel speed both cases with climbing lane and without climbing lane while increasing flow rate and the relevant column chart for ATS vs different flow rates shown in figure 4.4

Table 4.4 Average travel speed for Climbing lane with and without scenarios for different flow rates

Traffic flow rates (veh/hr)	**With climbing lane**	**Without climbing lane**
	ATS (m/s)	ATS (m/S)
578	2.4	2.3
598	2.31	2.15
618	2.25	1.96
638	2.02	1.84
658	1.90	1.79
678	1.86	1.72

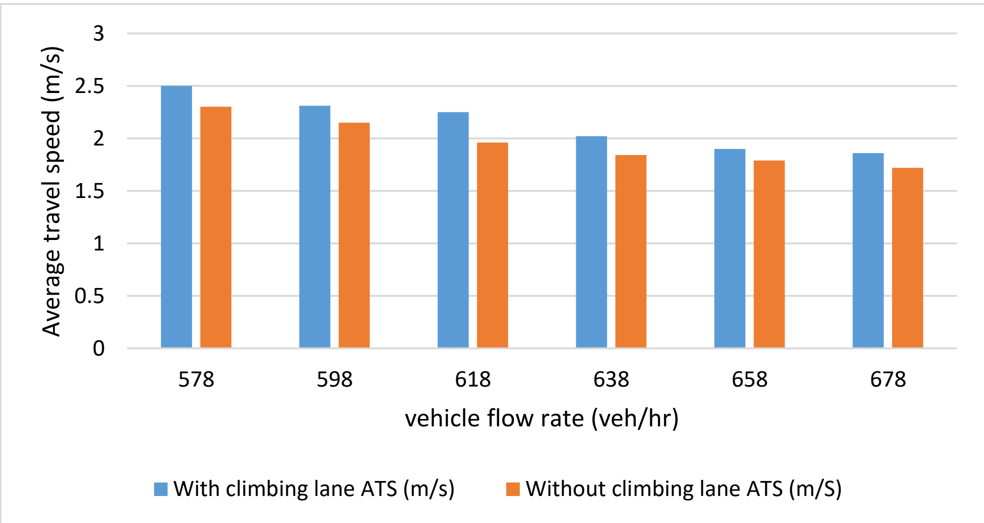

Figure 4.4 Average travel speed for Climbing lane with and without scenarios Vs flow rate

4.5 Climbing Lane Length

Deciding Climbing lane geometry is one of the important things when planning climbing lanes for two-way highways. For this study it has evaluated the effect of climbing lengths for its operational performance based on total delay time and average travel speed. For simulation model it has considered 10% fixed heavy occupancy vehicle percentage from the total flow and effect has been considered for different flow rates and different climbing lane lengths. Table 4.5 shows the total delay time for the climbing lane section for fixed HOVs for different flow rates. Here considered the increasing flow rates by 20 vehicles per hour from the observed flow rate from the video at the climbing lane section.

When increasing the traffic volume, it is shown that vehicle delay has been increased. And also, it shows that increase of vehicle delay when increasing climbing lane length. It already discussed the vehicle delay due to traffic volume in above.

Table 4.5 The total delay time for the climbing lane for fixed HOVs for different flow rates

	Climbing lane length (m)			
Vehicle flow rate (veh/hr)	Ln 1 (391)	Ln 2 (420)	Ln 3(464)	Ln 4 (524)
578	47	49	49	49
598	48	52	52	53
618	51	52	54	56
638	54	55	55	54
658	55	57	56	57
678	56	58	58	60

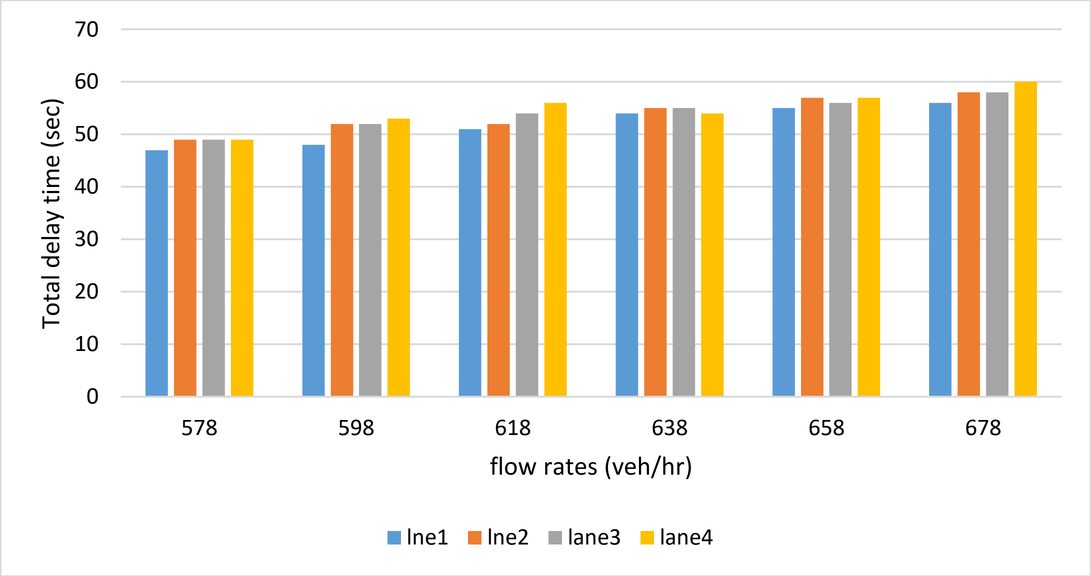

Figure 4.5 total vehicle delays for climbing lane for different lane lengths flow rates

It is interesting to inspect further increasing vehicle delay due to increasing climbing lane length. It is a positive impact that when increasing climbing lane length, the travel time may increase according to the following equation.

$$Average\ travel\ Speed\ = \frac{Distance}{time}$$

Hence for fixed HOVs rate (10%) following ATS results were tabulated due to changing of traffic flow rate with different climbing lane length. Then it is observed speed increasing due to increase of climbing lane lengths as shown in table 4.6

Table 4.6 Average travel speed for different climbing lane lengths for different flow rates

	Climbing lane length (m)			
Vehicle flow rate (veh/hr)	391	420	464	524
578	2.4	2.49	2.67	2.94
598	2.33	2.4	2.58	2.82
618	2.25	2.31	2.49	2.73
638	2.2	2.26	2.48	2.77
658	2.14	2.2	2.38	2.59
678	2.1	2.16	2.32	2.56

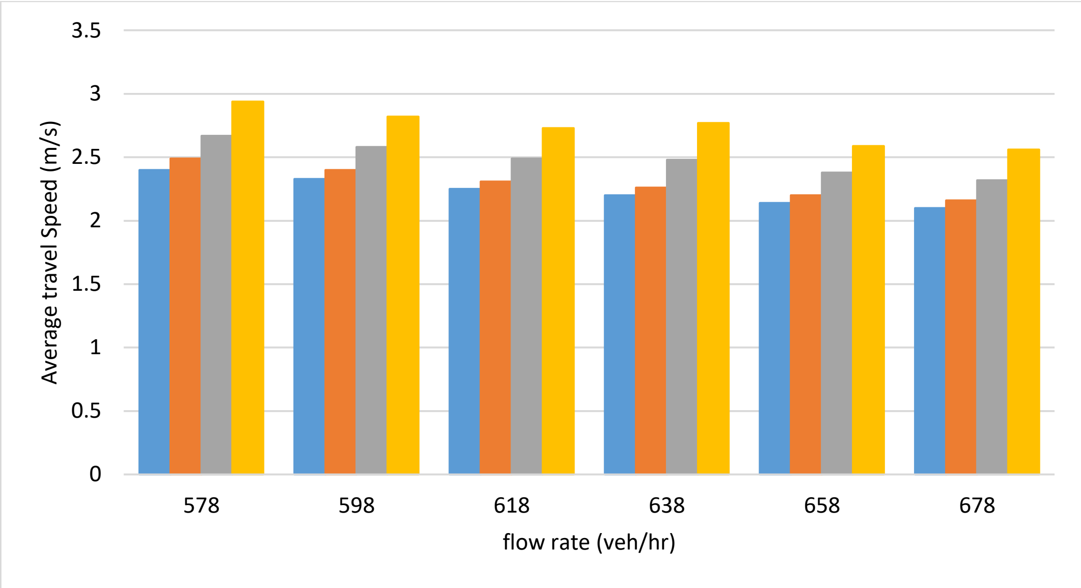

Figure 4.6 Average time speed with different climbing lane lengths for different flow rates

4.6 Discussion

According to the design standards of Road development Authority Sri Lanka (RDA,2000) the design speed of the two-lane highways is about 80km/hr. the total road considered with many different gradient sections. Because from 2/3 of the total road length falls along in high elevation zone in the country. Therefore, with the increasing traffic volumes and HOVs percentages implication of climbing lanes for elevated gradient sections is essential for better operational performance and safety. But this study only done for evaluation the operational performance of the application of climbing lane section along the CRWB two-way highway. The operational performance was evaluated using total delay time and for average travel speed.

Sri Lankan has less data collection of applying climbing lanes in road network due to less availability of climbing lane sections in road network. Therefore, many foreign literatures were referred to plan the methodology. It was difficult to get real time data at the considered location due to placing high-tech camera system at the location of the considered climbing lane section along CRWB highway. Therefore, traffic enumerators were used at two locations at the beginning of the climbing lane section and the end of the climbing lane section. With the collected data simulation models were developed using a popular microsimulation software called VISSIM. According to the simulation results as shown above the considered parameters for performance evaluation total delay time, Average travel speed for different Heavy occupancy vehicle ratios and for different flow rates indicates that with the presence of climbing lane the operational performance of two-lane highway will significantly increase.

For the model simulation the initial geometric condition considered for climbing lane was 6% average gradient and 391m climbing lane length. The considered traffic information was vehicle flow rate of initial value as 578veh/hr (which was observed from the traffic enumerators) and 9.1% of heavy occupancy vehicle ratio.

Two models have been developed and simulated to evaluate the operational performance due to the different traffic flow characteristics and climbing lane geometric characteristics.

Considering the model developed for evaluating effect of traffic flow characteristics it was observed for fixed 10% Heavy Occupancy Vehicles (HOVs) ratio and for 578veh/hr flow rate the the total delay observed for climbing lane with scenario was 44 sec and for climbing lane without scenario is 60 secs. Therefore, time saving by the climbing lane application is 16secs indicating over 25% delay reduction. The average travel speed has been obtained using the time consumed to complete the climbing lane section and the climbing lane length. Travel time taken to travel the climbing lane length was obtained from the simulation model and average travel speed was calculated. For the climbing lane scenario for 10% fixed Heavy occupancy vahicles ratio and for 578veh.hr vehicle flow rate, it was observed 2.4m/s average travel speed. But for no climbing lane scenario the average travel speed obtained was 2.2m/s. it is nearly 10% speed increment with the presence of climbing lane in two-lane highway section along the CRWB highway.

When considering the variation of heavy occupancy vehicles on climbing lanes. The total delay time is increasing with the increasing heavy occupancy vehicle ratio for a fixed flow rate of 578veh/hr. With the increasing of HOVs ratio from 9.1% to 25.2% considering 20 heavy occupancy vehicles will join to the vehicle flow at a time, the total delay is increasing from 44 seconds to 55 seconds. It is 20% increasing of time compared to the initial value. And for no climbing lane scenario for the same situation the delay time is increasing from 60sec to 68 seconds. It is 13% increment to the initial value of 60seconds. This means with more HOVs the more will divert to the climbing lane increasing the flow in climbing lane. Therefore, the delay is increasing. But compare to the no climbing lane scenario still the delay time is lower with the presence climbing lane.

The average speed of a vehicle with the presence of climbing lane has decreased from 2.4m/s to 2.11 m/s with the increasing of HOVs ratio from 9.1% to 25.2%. it is 12% speed reduction compared to the initial speed. It is obvious that when more heavy occupancy vehicles divert to the climbing lane the average speed will decreased. The no climbing lane scenario the average travel speed varies from 2.26m/s to 1.97 m/s. But compared to the no climbing lane scenario the average speed of a vehicle is still higher value.

Considering the effect of flow rate to the total delay time and for the average travel speed with 10% fixed HOVs ratio, it is observed that the delay will increase when the vehicle flow rate increasing. The considerable percentage of delay increment is for presence of climbing lane scenario is 27% compared to the initial value of (from 44sec up to 56 sec). and for no climbing lane scenario the value decreasing is 21% compared to the initial value (from 60sec to 73 sec).

The effect to the average travel speed by varying the flow rate from 578veh/hr to 678veh/hr, for 10% fixed HOVs ratio showed than when increasing the flow rate, the average travel speed is decreasing. But compared to the no climbing lane scenario it is quite higher value. But when there is more flow rate like 800veh/hr the climbing lane may not perform well as expected. It shows in figure 4.4.

For this study the second model has been developed to evaluate the effect of climbing lane geometry on the performance of climbing lane. We here considered only the climbing lane length. But climbing lane geometry also worth to evaluate. As the model results when the climbing lane length is increasing for fixed 6% slope gradient, and for fixed 10% HOVs ratio. It shows that the delay is increasing when the length of CL is increasing. But average travel speed is increasing therefore for operational performance the effect on the climbing a length is considerably low. But as per the design guide lines for average 6% gradient 391m climbing lane length would be appropriate.

As a summary considering the simulation results of the two models the operational performance of the climbing lane is considerably higher for two-lane highways in Sri Lanka. This has been discovered by modeling the existing climbing lane along the CRWB two-way highway section. Therefore, to cater the increasing traffic and increasing heavy occupancy flow rates introducing climbing lanes for the places where there has higher slope gradient would enhance the operational capacity of the two-lane highway. It is a better solution for Road Development Authority instead for finding funds for complete road improvement.

5 CONCLUSION AND RECOMMENDATIONS

High gradient mountainous sections have a severe traffic and safety issues due to inadequate overtaking opportunities when passing slow moving vehicles causing light vehicles have to drive in very low speed behind heavy vehicles. According to the records of traffic conditions along the CRWB Highway during the past decade, the number of trucks and other heavy vehicles including recreational vehicles had been increasing. This has decreased the quality of service and safety of the existing facilities. To overcome this situation, increasing the road capacity by adding extra lane, increasing shoulder width and length is highly essential. However, the lack of time and fund that could be allocated generally demotivates these projects. Therefore, climbing lane will be a better solution for this issue as it would be low cost and less time consuming. In spite of that CRWB consist of many upgrade and down grade sections along the whole rout length. Hence, there is a severity of introducing more climbing lane sections along the total route length enhance its operational performance due to increasing traffic volume and the increasing heavy vehicles.

Hence, this study was aimed to evaluate the operational performance of implementation of climbing lanes on two-lane highways along CRWB as a solution to increasing traffic problems in Sri Lankan roads.

As per the ASSHTO guideline, that discusses warrants for climbing lane, defines the requirements for climbing lane in terms of flow rate, heavy vehicle flow rate, heavy vehicle speed and LOS. The Road Development Authority Sri Lanka has also discussed climbing lane length in geometric designed standard.

To evaluate the performance of the climbing lane, hypothetical scenarios were developed using VISSIM software and analyzed. The data required for the model development was obtained through traffic survey. The hypothetical scenarios were analyzed for different roadway geometries like climbing lane length so as analysis were done for different traffic characteristics such as different traffic flow rates and different heavy occupancy vehicle percentages.

The parameters used for evaluation of operational performance were Average travel speed and total delay time. Analysis were done for presence of climbing lane and without climbing lane situation and parameter values obtained were compared for discussion.

According to the model results, vehicle delay time has decreased from 25% from the value of climbing lane without scenario. Hence climbing lane has a significant impact on enhancing the operational efficiency by reducing vehicle total delay time.

Further, from numerical simulation after implementing climbing lane to the two-lane CRWB highway section, average travel speed has increased for total traffic. According to the observed results average travel speed have increased by 8% compared to the no climbing lane situation. These two values were obtained for the existing climbing lane geometry (6% slope gradient and 391m climbing lane length) and for the present traffic flow characteristics (for 10% HOVs ratio and 578 veh/hr).

It has observed that HOVs ratio in total traffic flow has a huge impact on the operational performance of two-way road section in CRWB highway. With the increasing of HOVs ratios the total delay time of a vehicle has increased. But compared to the climbing lane without scenario to the presence of climbing lane scenario, the time saving by adding climbing has reaching in to its maximum limit. The average travel speed also has been increased by adding climbing lane to the considered roadway section in CRWB highway. But the with the increasing of HOVs ratio the increasing of average travel speed has reaching its maximum limit. Therefore, more if there would more than 30% HOVs ratio in the traffic flow the presence of climbing lane section will not make any significant to road way section. Therefore, adding new lanes for the road way section recommended.

When the flow rate increasing as expected the total delay time of a vehicle has been increased though you have increased the climbing lane. But it was lesser compared to the no climbing lane situation. But when the flow rate closed to the maximum limit (1200 PCU/hr) the difference of delay time will be minimizing. In the climbing lane section, the traffic flow rate has a certain impact on its capacity. when there is low flow rate lesser amount of vehicle will divert to climbing lane. When larger the flow rates more vehicle would divert to climbing lane that results higher traffic density in climbing lane. Therefore, adding new lanes for the road way section recommended.

Considering the geometry of the existing climbing lane, the impact due to slope gradient did not consider on operational performance of climbing lane due to lack data collection limited time availability for the study. But it has evaluated the operational performance for different lengths of the climbing lane. For fixed slope gradient the longer climbing lane length lower the average travel speed of a vehicle on CRWB highway.

5.1 Recommendation

This study focuses on the operation performance of adding climbing lane section along two-lane highways in Sri Lanka. While evaluating the operational performance, it's worth to evaluate the safety performance of the climbing lane is so essential. But with the lack of real trajectory data in Sri Lanka it is difficult to evaluate the safety performance in climbing lane from this study. Hence for future researches its worth to evaluate the safety performance of the climbing lanes by collecting more real time data in the field for a long duration. In Sri Lankan road conditions, it is quite difficult to evaluate the LOS criteria guidelines published by HCM (2000) for performance evaluation of climbing lanes. For future studies it is worth to develop a guideline to evaluate the LOS of climbing lanes performance using Sri Lankan standards.

This study limited parameters were considered for evaluation of the performance of climbing lanes. There are more parameters possible for further studies, such as Time to collision, vehicle length, no of accidents in the section, geometric properties like slope gradient, etc

The climbing lane sections are less popular in Sri Lankan road network. Therefore, there are a smaller number of climbing lanes exist in Sri Lankan roads. This leads to have less studies availability in the particular topic. But there are many road sections that adding climbing lane is essential for enhancing the capacity of the two-lane highways. To plan more climbing lanes on two-lane highways more data collection should require to plan, model, calibrate and validate climbing lane sections in future.

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APPENDIX A

Table A1: Traffic Count Data –Down Direction

Passing lane CRWB																
Classified Flow - Down direction																
										Location	: Pathulpar	O				
										Movement :		PS				
Date : 2019-08-09										From	:	P			To : S	
	0.5	0.8	1	1.6	1.7	1.8	1.5	1.6	1.7	2.8	2.8	2.8	2.8	2.8	3.4	
Time	**Motor Bike**	**3-Wheeler**	**Car/ Jeep**	**Pasenger Van**	**Medium Bus**	**Large Bus**	**Light Goods Vehicle**	**Lorry**	**Large Lorry**	**3 - Axle Rigid**	**3 - Axle Art.**	**4 - Axle Art.**	**5 - Axle Art.**	**6 - Axle Art.**	**Farm Vehicle**	**Total**
06.00 - 06.15																
06.15 - 06.30																
06.30 - 06.45																
06.45 - 07.00																
07.00 - 07.15	51	27	39	18	5	28	8	8	8	8	0	1	0	0	1	
07.15 - 07.30	49	24	31	23	9	14	18	9	11	5	0	0	0	0	0	
07.30 - 07.45	41	21	42	28	8	18	10	13	14	6	1	0	1	0	0	
07.45 - 08.00	55	20	47	17	5	26	12	9	12	4	1	0	0	1	1	
08.00 - 08.15	48	25	40	19	5	19	9	12	9	7	0	2	1	0	0	
08.15 - 08.30	45	25	45	25	7	20	12	10	12	6	0	1	0	0	0	
08.30 - 08.45	54	19	39	21	5	22	9	9	10	6	0	0	0	0	1	
08.45 - 09.00	38	29	41	18	4	17	11	12	13	4	0	0	1	1	1	
09.00 - 09.15	41	28	48	28	6	21	14	11	10	7	1	2	0	0	0	
09.15 - 09.30	39	25	40	24	4	18	13	8	12	4	2	0	1	0	0	
09.30 - 09.45	34	23	39	21	5	19	10	12	10	6	0	0	1	1	1	
09.45 - 10.00	35	24	41	19	4	17	12	10	11	5	1	1	0	0	1	
10.00 - 10.15	37	21	42	22	5	23	14	11	13	6	0	1	1	0	0	
10.15 - 10.30	29	28	39	19	4	18	9	10	10	4	1	1	0	0	1	
10.30 - 10.45	32	2	36	21	6	19	10	10	13	7	0	0	0	0	0	
10.45 - 11.00	38	19	40	18	5	17	9	8	11	4	0	0	0	0	1	
11.00 - 11.15	29	21	20	13	2	13	8	2	2	2	0	0	1	0	0	
11.15 - 11.30	37	18	24	17	3	12	5	2	4	3	0	0	0	0	0	
11.30 - 11.45	30	19	23	14	4	14	4	3	3	3	0	2	0	2	1	
11.45 - 12.00	31	17	21	16	2	12	7	4	5	2	1	2	1	0	0	
12.00 - 12.15	15	8	25	13	2	7	6	4	2	0	0	2	1	0	0	
12.15 - 12.30	17	9	22	10	1	10	4	5	3	1	0	0	0	0	0	
12.30 - 12.45	16	11	28	14	2	8	5	4	2	3	0	0	0	0	1	
12.45 - 13.00	14	8	24	12	0	9	5	2	5	1	0	1	1	1	1	
13.00 - 13.15	19	11	32	9	1	7	4	5	4	0	1	1	0	0	0	
13.15 - 13.30	15	9	31	8	2	7	4	4	4	1	0	0	0	1	1	
13.30 - 13.45	8	18	29	9	3	6	6	7	5	1	0	0	1	0	1	
13.45 - 14.00	18	14	32	8	0	9	2	6	6	1	1	0	1	0	0	
14.00 - 14.15	17	10	39	10	2	8	4	7	3	0	1	0	0	0	0	
14.15 - 14.30	15	13	31	10	1	8	4	6	5	0	0	2	0	1	0	
14.30 - 14.45	18	11	34	12	0	6	4	8	5	0	0	2	0	0	0	
14.45 - 15.00	14	10	29	8	1	9	5	9	6	0	1	2	1	0	0	
15.00 - 15.15	18	14	39	9	1	8	4	8	5	1	0	0	1	0	1	
15.15 - 15.30	17	10	29	11	0	7	5	7	3	1	1	0	0	1	1	
15.30 - 15.45	19	11	31	8	2	6	4	9	3	2	0	0	0	0	0	
15.45 - 16.00	25	12	27	8	1	9	7	11	6	3	0	0	0	0	0	
16.00 - 16.15	28	18	48	12	1	11	12	10	4	3	1	0	0	0	0	
16.15 - 16.30	21	14	41	10	1	9	11	11	8	1	0	0	1	0	1	
16.30 - 16.45	19	17	44	11	4	12	9	7	5	3	0	1	0	0	1	
16.45 - 17.00	25	19	39	14	3	12	4	9	7	3	0	1	0	0	0	
17.00 - 17.15	23	14	43	10	0	10	7	12	5	1	1	1	1	1	1	
17.15 - 17.30	22	14	40	10	2	9	9	7	4	2	0	1	1	0	0	
17.30 - 17.45	25	16	42	12	3	10	8	9	8	2	1	1	0	1	0	
17.45 - 18.00	22	15	45	14	4	10	9	10	5	2	2	0	0	0	1	
18.00 - 18.15	26	17	41	12	1	11	11	11	6	3	1	0	0	0	1	
18.15 -18.30	21	10	39	10	3	9	5	8	5	1	3	0	0	0	0	
18.30 - 18.45	18	14	42	15	1	12	6	10	4	1	0	0	1	1	0	
18.45 - 19.00	28	18	48	18	2	8	8	12	7	2	1	0	1	0	0	
19.00 - 19.15																
19.15 - 19.30																
19.30 - 19.45																
19.45 - 20.00																

Table A2: Traffic Count Data –Climbing Lane

Passing lane CRWB																
Classified Flow -Climbing lane																
										Location : Pathulpar		**O**				
										Movement :		**PG**				
Date : 2019-08-09										**From :**		**P**		**To : G**		
	0.5	**0.8**	**1**	**1.6**	**1.7**	**1.8**	**1.5**	**1.6**	**1.7**	**2.8**	**2.8**	**2.8**	**2.8**	**2.8**	**3.4**	
Time	**Motor Bike**	**3-Wheeler**	**Car/ Jeep**	**Pasenger Van**	**Medium Bus**	**Large Bus**	**Light Goods Vehicle**	**Lorry**	**Large Lorry**	**3 - Axle Rigid**	**3 - Axle Art.**	**4 - Axle Art.**	**5 - Axle Art.**	**6 - Axle Art.**	**Farm Vehicle**	**Total**
06.00 - 06.15																
06.15 - 06.30																
06.30 - 06.45																
06.45 - 07.00																
07.00 - 07.15	21	19	18	2	1	2	4	5	4	2	0	0	1	0	1	
07.15 - 07.30	25	21	20	4	3	1	2	4	7	1	0	0	1	0	0	
07.30 - 07.45	23	25	24	3	1	1	3	7	5	0	2	0	0	0	1	
07.45 - 08.00	26	23	22	4	3	3	4	7	7	1	2	0	1	0	0	
08.00 - 08.15	21	15	19	3	2	2	2	4	3	0	0	0	0	0	1	
08.15 - 08.30	23	21	12	2	0	1	5	5	4	2	1	1	1	1	0	
08.30 - 08.45	18	14	18	0	1	3	4	4	9	3	2	0	1	0	0	
08.45 - 09.00	16	12	13	1	2	2	6	8	7	1	2	0	0	0	1	
09.00 - 09.15	10	14	11	0	1	1	4	4	6	2	1	0	0	0	0	
09.15 - 09.30	14	12	10	2	1	1	3	7	5	2	1	1	1	0	0	
09.30 - 09.45	10	10	13	1	0	3	5	5	4	1	0	0	0	0	1	
09.45 - 10.00	12	10	9	0	1	2	4	6	6	0	0	0	1	0	0	
10.00 - 10.15	16	11	10	1	0	2	4	7	7	0	1	0	0	1	0	
10.15 - 10.30	14	14	7	0	1	1	6	5	6	1	1	1	1	0	0	
10.30 - 10.45	10	12	18	1	1	2	3	5	5	0	1	0	0	0	1	
10.45 - 11.00	12	11	10	0	0	1	3	8	4	0	0	0	0	0	0	
11.00-11.15	12	10	11	0	0	0	1	5	5	1	0	1	1	0	0	
11.15-11.30	10	14	9	0	1	1	2	4	2	0	1	0	0	0	0	
11.30-11.45	14	11	8	0	0	1	2	4	4	0	1	0	0	0	1	
11.45-12.00	16	14	13	1	0	2	3	5	5	0	0	1	1	1	0	
12.00-12.15	12	15	8	1	1	1	1	3	2	1	0	0	1	0	1	
12.15-12.30	10	11	9	0	1	1	0	4	3	1	1	0	1	0	0	
12.30-12.45	12	14	8	2	0	0	0	3	2	1	1	1	1	0	1	
12.45-13.00	14	12	11	3	0	0	2	0	0	0	0	0	1	0	0	
13.00-13.15	17	17	8	4	1	1	1	4	5	1	1	0	0	0	1	
13.15-13.30	18	18	8	7	1	0	0	6	4	0	1	0	0	1	0	
13.30-13.45	16	15	12	9	0	0	1	5	5	1	1	1	0	0	0	
13.45-14.00	20	22	14	8	1	0	0	0	3	0	0	0	0	0	1	
14.00 - 14.15	18	18	10	5	0	1	1	6	4	0	0	0	1	0	1	
14.15 - 14.30	16	17	9	7	0	1	1	4	5	1	0	0	0	0	0	
14.30 - 14.45	19	21	12	6	1	1	2	6	4	1	0	1	0	0	0	
14.45 - 15.00	17	16	13	8	0	2	1	7	6	0	0	0	0	0	0	
15.00 - 15.15	20	19	11	5	1	2	1	6	5	0	0	0	0	1	1	
15.15 - 15.30	21	16	9	5	1	1	1	5	4	0	0	0	0	0	0	
15.30 - 15.45	20	26	14	7	0	2	3	7	6	1	0	1	1	0	0	
15.45 - 16.00	24	23	10	6	0	1	1	6	5	2	1	0	0	0	0	
16.00 - 16.15	21	17	13	6	2	2	2	8	6	0	0	0	1	0	1	
16.15 - 16.30	23	19	15	8	0	3	2	6	4	1	0	0	0	1	1	
16.30 - 16.45	31	28	17	5	1	3	1	5	8	2	0	1	1	0	0	
16.45 - 17.00	25	31	19	6	2	2	4	7	7	0	1	0	0	0	0	
17.00 - 17.15	22	16	18	7	2	2	3	10	6	1	2	0	0	0	0	
17.15 - 17.30	24	18	15	7	3	3	2	5	6	2	4	0	1	0	1	
17.30 - 17.45	30	40	9	6	1	3	4	12	7	0	4	0	1	0	0	
17.45 - 18.00	38	23	12	8	1	5	5	7	5	1	2	1	0	0	0	
18.00 - 18.15	31	45	7	3	2	2	2	9	4	1	3	1	1	0	1	
18.15 -18.30	29	38	13	5	1	4	4	6	5	3	1	0	2	0	0	
18.30 - 18.45	33	28	8	2	3	3	3	10	8	2	2	0	0	1	0	
18.45 - 19.00	34	35	12	4	2	2	5	14	9	1	2	0	1	0	1	
19.00 - 19.15																
19.15 - 19.30																
19.30 - 19.45																
19.45 - 20.00																

Table A3: Traffic Count Data –Normal lane

Passing lane CRWB

Classified Flow

										Location : Pathulpana		O				
										Movement :		PS				
Date : 2019-08-09										From :		P			To : S	
	0.5	0.8	1	1.6	1.7	1.8	1.5	1.6	1.7	2.8	2.8	2.8	2.8	2.8	3.4	
Time	Motor Bike	3-Wheeler	Car/ Jeep	Pasenger Van	Medium Bus	Large Bus	Light Goods Vehicle	Lorry	Large Lorry	3 - Axle Rigid	3 - Axle Art.	4 - Axle Art.	5 - Axle Art.	6 - Axle Art.	Farm Vehicle	Total
06.00 - 06.15																
06.15 - 06.30																
06.30 - 06.45																
06.45 - 07.00																
07.00 - 07.15	5	1	31	9	1	15	3	3	4						0	
07.15 - 07.30	4	2	29	7	1	12	1	3	3						0	
07.30 - 07.45	4	1	25	11	0	12	2	2	3						0	
07.45 - 08.00	2	2	28	9	2	9	3	1	1						0	
08.00 - 08.15	5	2	26	11	1	13	2	2	4						0	
08.15 - 08.30	4	1	18	8	0	12	1	1	3						0	
08.30 - 08.45	3	4	23	12	0	8	3	2	2						0	
08.45 - 09.00	7	2	19	9	2	10	1	2	1						0	
09.00 - 09.15	8	4	28	8	1	8	2	1	3						0	
09.15 - 09.30	6	1	25	10	0	6	0	2	1						0	
09.30 - 09.45	3	2	23	8	0	7	0	0	1						0	
09.45 - 10.00	5	3	21	7	1	9	1	1	2						0	
10.00 - 10.15	2	3	18	7	1	9	1	1	1						0	
10.15 - 10.30	5	2	22	8	0	6	0	0	1						0	
10.30 - 10.45	3	3	19	10	0	8	1	1	1						0	
10.45 - 11.00	4	1	20	8	1	7	2	2	2						0	
11.00 - 11.15	1	0	22	6	0	5	0	1	1						1	
11.15 - 11.30	3	1	18	8	0	7	1	2	0						0	
11.30 - 11.45	2	2	19	7	1	6	2	0	1						0	
11.45 - 12.00	3	1	21	9	0	8	1	1	2						1	
12.00 - 12.15	1	2	17	7	1	6	2	2	1						0	
12.15 - 12.30	0	0	19	11	0	7	0	1	0						1	
12.30 - 12.45	0	1	15	9	0	6	0	0	1						0	
12.45 - 13.00	1	2	16	8	1	7	0	0	1						1	
13.00 - 13.15	1	0	38	16	1	19	1	1	0						1	
13.15 - 13.30	0	0	35	14	0	14	0	1	0						0	
13.30 - 13.45	0	0	41	21	0	16	0	0	1						1	
13.45 - 14.00	0	0	37	19	1	12	0	0	1						0	
14.00 - 14.15	0	1	40	17	0	15	1	0	1						0	
14.15 - 14.30	1	1	38	18	0	16	0	0	0						0	
14.30 - 14.45	1	0	35	20	0	17	1	2	0						0	
14.45 - 15.00	1	0	41	19	1	12	1	2	1						0	
15.00 - 15.15	1	0	42	18	0	17	0	1	1						0	
15.15 - 15.30	0	1	40	21	1	15	0	1	0						0	
15.30 - 15.45	0	0	38	17	0	13	0	2	2						0	
15.45 - 16.00	0	0	49	19	0	10	1	1	1						0	
16.00 - 16.15	0	0	47	22	1	17	0	3	4						0	
16.15 - 16.30	0	0	41	19	1	21	0	2	2						0	
16.30 - 16.45	1	1	39	17	0	18	0	3	3						0	
16.45 - 17.00	0	1	52	21	0	20	1	1	5						0	
17.00 - 17.15	0	0	41	19	2	21	1	1	1						0	
17.15 - 17.30	0	0	47	17	3	18	0	4	4						0	
17.30 - 17.45	1	1	51	16	0	17	0	3	3						0	
17.45 - 18.00	0	1	49	23	1	21	0	1	4						0	
18.00 - 18.15	0	3	50	25	3	20	0	3	4						0	
18.15 -18.30	0	1	48	23	2	18	1	4	3						0	
18.30 - 18.45	0	1	53	19	2	21	0	4	4						0	
18.45 - 19.00	1	0	42	28	1	23	0	2	2						0	
19.00 - 19.15																
19.15 - 19.30																
19.30 - 19.45																
19.45 - 20.00																
12 Hour Total																

APPENDIX B

Table B1: Traffic count data arrange for 1 hr simulation for climbing lane

Passing lane CRWB																
Classified Flow -Climbing lane																
											Location : Pathulpar		O			
											Movement :		PG			
Date : 2019-08-09											From :		P		To : G	
	0.5	0.8	1	1.6	1.7	1.8	1.5	1.6	1.7	2.8	2.8	2.8	2.8	2.8	3.4	
Time	Motor Bike	3-Wheeler	Car/ Jeep	Pasenger Van	Medium Bus	Large Bus	Light Goods Vehicle	Lorry	Large Lorry	3 - Axle Rigid	3 - Axle Art.	4 - Axle Art.	5 - Axle Art.	6 - Axle Art.	Farm Vehicle	Total
06.00 - 06.15																
06.15 - 06.30																
06.30 - 06.45																
06.45 - 07.00																
07.00 - 07.15	21	19	18	2	1	2	4	5	4	2	0	0	1	0	1	
07.15 - 07.30	25	21	20	4	3	1	2	4	7	1	0	0	1	0	0	
07.30 - 07.45	23	25	24	3	1	1	3	7	5	0	2	0	0	0	1	
07.45 - 08.00	26	23	22	4	3	3	4	7	7	1	2	0	1	0	0	
08.00 - 08.15	21	15	19	3	2	2	2	4	3	0	0	0	0	0	1	
08.15 - 08.30	23	21	12	2	0	1	5	5	4	2	1	1	1	1	0	
	93	84	77	12	6	7	14	23	19	3	5	1	2	1	2	
08.30 - 08.45	18	14	18	0	1	3	4	4	9	3	2	0	1	0	0	
08.45 - 09.00	16	12	13	1	2	2	6	8	7	1	2	0	0	0	1	
09.00 - 09.15	10	14	11	0	1	1	4	4	6	2	1	0	0	0	0	
09.15 - 09.30	14	12	10	2	1	1	3	7	5	2	1	1	1	0	0	
09.30 - 09.45	10	10	13	1	0	3	5	5	4	1	0	0	0	0	1	
09.45 - 10.00	12	10	9	0	1	2	4	6	6	0	0	0	1	0	0	
10.00 - 10.15	16	11	10	1	0	2	4	7	7	0	1	0	0	1	0	
10.15 - 10.30	14	14	7	0	1	1	6	5	6	1	1	1	1	0	0	
10.30 - 10.45	10	12	18	1	1	2	3	5	5	0	1	0	0	0	1	
10.45 - 11.00	12	11	10	0	0	1	3	8	4	0	0	0	0	0	0	
11.00-11.15	12	10	11	0	0	0	1	5	5	1	0	1	1	0	0	
11.15-11.30	10	14	9	0	1	1	2	4	2	0	1	0	0	0	0	
11.30-11.45	14	11	8	0	0	1	2	4	4	0	1	0	0	0	1	
11.45-12.00	16	14	13	1	0	2	3	5	5	0	0	1	1	1	0	
12.00-12.15	12	15	8	1	1	1	1	3	2	1	0	0	1	0	1	
12.15-12.30	10	11	9	0	1	1	0	4	3	1	1	0	1	0	0	
12.30-12.45	12	14	8	2	0	0	0	3	2	1	1	1	1	0	1	
12.45-13.00	14	12	11	3	0	0	2	0	0	0	0	0	1	0	0	
13.00-13.15	17	17	8	4	1	1	1	4	5	1	1	0	0	0	1	
13.15-13.30	18	18	8	7	1	0	0	6	4	0	1	0	0	1	0	
13.30-13.45	16	15	12	9	0	0	1	5	5	1	1	1	0	0	0	
13.45-14.00	20	22	14	8	1	0	0	0	3	0	0	0	0	0	1	
14.00 - 14.15	18	18	10	5	0	1	1	6	4	0	0	0	1	0	1	
14.15 - 14.30	16	17	9	7	0	1	1	4	5	1	0	0	0	0	0	
14.30 - 14.45	19	21	12	6	1	1	2	6	4	1	0	1	0	0	0	
14.45 - 15.00	17	16	13	8	0	2	1	7	6	0	0	0	0	0	0	
15.00 - 15.15	20	19	11	5	1	2	1	6	5	0	0	0	0	1	1	
15.15 - 15.30	21	16	9	5	1	1	1	5	4	0	0	0	0	0	0	
15.30 - 15.45	20	26	14	7	0	2	3	7	6	1	0	1	1	0	0	
15.45 - 16.00	24	23	10	6	0	1	1	6	5	2	1	0	0	0	0	
16.00 - 16.15	21	17	13	6	2	2	2	8	6	0	0	0	1	0	1	
16.15 - 16.30	23	19	15	8	0	3	2	6	4	1	0	0	0	1	1	
16.30 - 16.45	31	28	17	5	1	3	1	5	8	2	0	1	1	0	0	
16.45 - 17.00	25	31	19	6	2	2	4	7	7	0	1	0	0	0	0	
17.00 - 17.15	22	16	18	7	2	2	3	10	6	1	2	0	0	0	0	
17.15 - 17.30	24	18	15	7	3	3	2	5	6	2	4	0	1	0	1	
17.30 - 17.45	30	40	9	6	1	3	4	12	7	0	4	0	1	0	0	
17.45 - 18.00	38	23	12	8	1	5	5	7	5	1	2	1	0	0	0	
18.00 - 18.15	31	45	7	3	2	2	2	9	4	1	3	1	1	0	1	
18.15 -18.30	29	38	13	5	1	4	4	6	5	3	1	0	2	0	0	
18.30 - 18.45	33	28	8	2	3	3	3	10	8	2	2	0	0	1	0	
18.45 - 19.00	34	35	12	4	2	2	5	14	9	1	2	0	1	0	1	
19.00 - 19.15																
19.15 - 19.30																
19.30 - 19.45																
19.45 - 20.00																

Table B2: Traffic count data arrange for 1 hr simulation for normal lane

Passing lane CRWB																
Classified Flow																
										Location	: Pathulpar	O				
										Movement :		PS				
Date : 2019-08-09										From	:	P			To : S	
	0.5	0.8	1	1.6	1.7	1.8	1.5	1.6	1.7	2.8	2.8	2.8	2.8	2.8	3.4	
Time	Motor Bike	3-Wheeler	Car/ Jeep	Pasenger Van	Medium Bus	Large Bus	Light Goods Vehicle	Lorry	Large Lorry	3 - Axle Rigid	3 - Axle Art.	4 - Axle Art.	5 - Axle Art.	6 - Axle Art.	Farm Vehicle	Total
06.00 - 06.15																
06.15 - 06.30																
06.30 - 06.45																
06.45 - 07.00																
07.00 - 07.15	5	1	31	9	1	15	3	3	4						0	
07.15 - 07.30	4	2	29	7	1	12	1	3	3						0	
07.30 - 07.45	4	1	25	11	0	12	2	2	3						0	
07.45 - 08.00	2	2	28	9	2	9	3	1	1						0	
08.00 - 08.15	5	2	26	11	1	13	2	2	4						0	
08.15 - 08.30	4	1	18	8	0	12	1	1	3						0	
normal lane	15	6	97	39	3	46	8	6	11	0	0	0	0	0	0	231
climbin g lane	93	84	77	12	6	7	14	23	19	3	5	1	2	1	2	347
	108	90	174	51	9	53	22	29	30	3	5	1	2	1		578
08.30 - 08.45	3	4	23	12	0	8	3	2	2						0	
08.45 - 09.00	`	2	19	9	2	10	1	2	1						0	
09.00 - 09.15	8	4	28	8	1	8	2	1	3						0	
09.15 - 09.30	6	1	25	10	0	6	0	2	1						0	
09.30 - 09.45	3	2	23	8	0	7	0	0	1						0	
09.45 - 10.00	5	3	21	7	1	9	1	1	2						0	
10.00 - 10.15	2	3	18	7	1	9	1	1	1						0	
10.15 - 10.30	5	2	22	8	0	6	0	0	1						0	
10.30 - 10.45	3	3	19	10	0	8	1	1	1						0	
10.45 - 11.00	4	1	20	8	1	7	2	2	2						0	
11.00 - 11.15	1	0	22	6	0	5	0	1	1						1	
11.15 - 11.30	3	1	18	8	0	7	1	2	0						0	
11.30 - 11.45	2	2	19	7	1	6	2	0	1						0	
11.45 - 12.00	3	1	21	9	0	8	1	1	2						1	
12.00 - 12.15	1	2	17	7	1	6	2	2	1						0	
12.15 - 12.30	0	0	19	11	0	7	0	1	0						1	
12.30 - 12.45	0	1	15	9	0	6	0	0	1						0	
12.45 - 13.00	1	2	16	8	1	7	0	0	1						1	
13.00 - 13.15	1	0	38	16	1	19	1	1	0						1	
13.15 - 13.30	0	0	35	14	0	14	0	1	0						0	
13.30 - 13.45	0	0	41	21	0	16	0	0	1						1	
13.45 - 14.00	0	0	37	19	1	12	0	0	1						0	
14.00 - 14.15	0	1	40	17	0	15	1	0	1						0	
14.15 - 14.30	1	1	38	18	0	16	0	0	0						0	
14.30 - 14.45	1	0	35	20	0	17	1	2	0						0	
14.45 - 15.00	1	0	41	19	1	12	1	2	1						0	
15.00 - 15.15	1	0	42	18	0	17	0	1	1						0	
15.15 - 15.30	0	1	40	21	1	15	0	1	0						0	
15.30 - 15.45	0	0	38	17	0	13	0	2	2						0	
15.45 - 16.00	0	0	49	19	0	10	1	1	1						0	
16.00 - 16.15	0	0	47	22	1	17	0	3	4						0	
16.15 - 16.30	0	0	41	19	1	21	0	2	2						0	
16.30 - 16.45	1	1	39	17	0	18	0	3	3						0	
16.45 - 17.00	0	1	52	21	0	20	1	1	5						0	
17.00 - 17.15	0	0	41	19	2	21	1	1	1						0	
17.15 - 17.30	0	0	47	17	3	18	0	4	4						0	
17.30 - 17.45	1	1	51	16	0	17	0	3	3						0	
17.45 - 18.00	0	1	49	23	1	21	0	1	4						0	
18.00 - 18.15	0	3	50	25	3	20	0	3	4						0	
18.15 -18.30	0	1	48	23	2	18	1	4	3						0	
18.30 - 18.45	0	1	53	19	2	21	0	4	4						0	
18.45 - 19.00	1	0	42	28	1	23	0	2	2						0	
19.00 - 19.15							0									
19.15 - 19.30																
19.30 - 19.45																
19.45 - 20.00																
12 Hour Total																

Table B3: Traffic count data arrange for 1 hr simulation for down direction lane

Passing lane CRWB

Classified Flow - down direction

Location : Pathulpar O

Movement : PS

Date : 2019-08-09

From : P

To : S

	0.5	0.8	1	1.6	1.7	1.8	1.5	1.6	1.7	2.8	2.8	2.8	2.8	2.8	3.4			
Time	**Motor Bike**	**3-Wheeler**	**Car/ Jeep**	**Pasenger Van**	**Medium Bus**	**Large Bus**	**Light Goods Vehicle**	**Lorry**	**Large Lorry**	**3 - Axle Rigid**	**3 - Axle Art.**	**4 - Axle Art.**	**5 - Axle Art.**	**6 - Axle Art.**	**Farm Vehicle**	**Total**	PCU Total	
06.00 - 06.15																		
06.15 - 06.30																		
06.30 - 06.45																		
06.45 - 07.00																		
07.00 - 07.15	51	27	39	18	5	28	8	8	8	8	0	1	0	0	1	202		
07.15 - 07.30	49	24	31	23	9	14	18	9	11	5	0	0	0	0	0	193		
07.30 - 07.45	41	21	42	28	8	18	10	13	14	6	1	0	1	0	0	203		
07.45 - 08.00	55	20	47	17	5	26	12	9	12	4	1	0	0	1	1	210	808	
08.00 - 08.15	48	25	40	19	5	19	9	12	9	7	0	2	1	0	0	196	802	
08.15 - 08.30	45	25	45	25	7	20	12	10	12	6	0	1	0	0	0	208	817	7.30 am to 8.30 am
	189	91	174	89	25	83	43	44	47	23	2	3	2	1	1			
08.30 - 08.45	54	19	39	21	5	22	9	9	10	6	0	0	0	0	1	195	809	
08.45 - 09.00	38	29	41	18	4	17	11	12	13	4	0	0	1	1	1	190	789	
09.00 - 09.15	41	28	48	28	6	21	14	11	10	7	1	2	0	0	0	217	810	
09.15 - 09.30	39	25	40	24	4	18	13	8	12	4	2	0	1	0	0	190	792	
09.30 - 09.45	34	23	39	21	5	19	10	12	10	6	0	0	1	1	1	182	779	
09.45 - 10.00	35	24	41	19	4	17	12	10	11	5	1	1	0	0	1	181	770	
10.00 - 10.15	37	21	42	22	5	23	14	11	13	6	0	1	1	0	0	196	749	
10.15 - 10.30	29	28	39	19	4	18	9	10	10	4	1	1	0	0	1	173	732	
10.30 - 10.45	32	2	36	21	6	19	10	10	13	7	0	0	0	0	0	156	706	
10.45 - 11.00	38	19	40	18	5	17	9	8	11	4	0	0	0	0	1	170	695	
11.00 - 11.15	29	21	20	13	2	13	8	2	2	2	0	0	1	0	0	113	612	
11.15 - 11.30	37	18	24	17	3	12	5	2	4	3	0	0	0	0	0	125	564	
11.30 - 11.45	30	19	23	14	4	14	4	3	3	3	0	2	0	2	1	122	530	
11.45 - 12.00	31	17	21	16	2	12	7	4	5	2	1	2	1	0	0	121	481	
12.00 - 12.15	15	8	25	13	2	7	6	4	2	0	0	2	1	0	0	85	453	
12.15 - 12.30	17	9	22	10	1	10	4	5	3	1	0	0	0	0	0	82	410	
12.30 - 12.45	16	11	28	14	2	8	5	4	2	3	0	0	0	0	1	94	382	
12.45 - 13.00	14	8	24	12	0	9	5	2	5	1	0	1	1	1	1	84	345	
13.00 - 13.15	19	11	32	9	1	7	4	5	4	0	1	1	0	0	0	94	354	
13.15 - 13.30	15	9	31	8	2	7	4	4	4	1	0	0	0	1	1	87	359	
13.30 - 13.45	8	18	29	9	3	6	6	7	5	1	0	0	1	0	1	94	359	
13.45 - 14.00	18	14	32	8	0	9	2	6	6	1	1	0	1	0	0	98	373	
14.00 - 14.15	17	10	39	10	2	8	4	7	3	0	1	0	0	0	0	101	380	
14.15 - 14.30	15	13	31	10	1	8	4	6	5	0	0	2	0	1	0	96	389	
14.30 - 14.45	18	11	34	12	0	6	4	8	5	0	0	2	0	0	0	100	395	
14.45 - 15.00	14	10	29	8	1	9	5	9	6	0	1	2	1	0	0	95	392	
15.00 - 15.15	18	14	39	9	1	8	4	8	5	1	0	0	1	0	1	109	400	
15.15 - 15.30	17	10	29	11	0	7	5	7	3	1	1	0	0	1	1	93	397	
15.30 - 15.45	19	11	31	8	2	6	4	9	3	2	0	0	0	0	0	95	392	
15.45 - 16.00	25	12	27	8	1	9	7	11	6	3	0	0	0	0	0	109	406	
16.00 - 16.15	28	18	48	12	1	11	12	10	4	3	1	0	0	0	0	148	445	
16.15 - 16.30	21	14	41	10	1	9	11	11	8	1	0	0	1	0	1	129	481	
16.30 - 16.45	19	17	44	11	4	12	9	7	5	3	0	1	0	0	1	133	519	
16.45 - 17.00	25	19	39	14	3	12	4	9	7	3	0	1	0	0	0	136	546	4pm to 5 pm
17.00 - 17.15	23	14	43	10	0	10	7	12	5	1	1	1	1	1	1	130	528	
17.15 - 17.30	22	14	40	10	2	9	9	7	4	2	0	1	1	0	0	121	520	
17.30 - 17.45	25	16	42	12	3	10	8	9	8	2	1	1	0	1	0	138	525	
17.45 - 18.00	22	15	45	14	4	10	9	10	5	2	2	0	0	0	1	139	528	
18.00 - 18.15	26	17	41	12	1	11	11	11	6	3	1	0	0	0	1	141	539	
18.15 -18.30	21	10	39	10	3	9	5	8	5	1	3	0	0	0	0	114	532	
18.30 - 18.45	18	14	42	15	1	12	6	10	4	1	0	0	1	1	0	125	519	
18.45 - 19.00	28	18	48	18	2	8	8	12	7	2	1	0	1	0	0	153	533	
19.00 - 19.15																0	392	
19.15 - 19.30																0	278	
19.30 - 19.45																0	153	
19.45 - 20.00																0	0	
12 Hour Total																	0	