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Evaluation of the Impact of Kerb Side Bus Stop on Traffic Speed under Mixed Traffic Conditions- A Case Study in Addis-Ababa City

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Abstract— *The number and type of bus stops provided on a road significantly influence the flow characteristics of traffic on the road. In the present study, three kerb side bus stops in Addis Ababa city of varying traffic volume, bus frequency, bus dwell time and effective road widths are considered to evaluate the reduction in speed due to kerb side bus stop under variable roadway and traffic conditions. The speed reduction is evaluated by conducting speed studies both at the bus stop and away from the bus stop. An attempt is made in this study to understand the reduction of speed at each of the selected bus stop. Different Regression modals are developed for various influencing parameters that affects the traffic speed. The developed modal will be useful for analysing the variation of traffic speed under variable bus frequencies, bus dwell times and effective road widths. Speed graphs are plotted based on influencing parameters for the sections of road, away from the bus stop and also at the bus stop. The results of study suggest that the influencing parameters of kerb side bus-stops indicates when traffic volume is 2000pcu/hr. for a BF=40, BDT=30sec, ERW=4m, the reduction of speed is observed to be 40% where some conditions with BDT=90sec, the speed reduction is 52%. A comparison of these graphs indicates the reduction in speed due to the kerb side bus stop. These findings can better inform planners about traffic speed modelling under mixed traffic conditions by helping them in accounting for the speed-reducing impacts of bus stops.*

Keywords— *Bus Frequency, % of speed reduction, Traffic volume, Bottleneck, Bus Dwell time, Effective Road Width.*

I. INTRODUCTION

All over the world, large cities and urban streets are becoming more congested. Mostly Ethiopia and India have heterogeneous traffic stream with commonly exist road traffic stream including motorized and non-motorized vehicles using the road lane for indicative purpose. Traffic flow of vehicles in most of the developing countries such as Ethiopia is heterogeneous or mixed traffic stream in nature, as member of different types of vehicles with their many variety of physical dimensions, weights and dynamic characteristics with these comprise the moving on any available part of given lane without any lane of road discipline actions taken place. Understanding of traffic speed characteristics with their various outputs because of factors is important requirement in the field of traffic engineering for safety and it indicates the quality of service experienced by the traffic stream.

The city Addis Ababa is the capital city of Ethiopia and located almost in the Center of the nation in the foothills of Mount Entoto about 2,500 m above sea level. As per the statistical records, the city of Addis Ababa has an estimated population of about 4 million inhabitants. The average decadal growth rate of population is estimated as around 3.8 percent. Nearly 1,000 city buses are running across the city Addis Ababa every day from 6:00 a.m. to 2:00 p.m.

The city Addis Ababa has the highest density of vehicles per kilometer with 831 vehicles per kilometer of road space, with more than 4484 new vehicles being added to the city roads every month, with approximately 100 new vehicles join the city roads every day, asper the statement given in the website of (www.thereporterethiopia.com). As per statistics, 44 percent of Addis Ababa population depends on public transportation, especially towards to Anbessa buses. The city traffic in peak hours is subjected to a lot of congestion and delay with very low journey speed as low as 25Kmph. Frequent weaving movements of buses and trucks in busy corridors have a significant effect on the speed of traffic. Further, stoppage of buses in the direction of traffic at the bus stops tends to block the traffic moving on the left lane, cause bottle neck.

II. NEED FOR THE PRESENT STUDY

Under mixed traffic conditions in Addis Ababa city, most of the bus stops are located at kerb side thus causing a reduction on speed of other vehicles. This increase the operational delay on other vehicles and reduce the speed. Due to lack understanding and stop discipline, the bus drivers stop the buses without utilizing the available road space effectively. The corridor of Addis Ababa city kerb side bus stops are forced to occupy certain part of road especially in peak hours, thus causing a lot of speed reduction in other vehicles.

When the buses stop on the road at a kerb side bus stop, some of the carriage way is loss depending on the position where the bus is stopped, thus reducing the effective road width available for the other traffic. The reduction in the carriage way have impact on traffic speed of other vehicles creating bottleneck situation. The evaluation on the impact of kerb side bus stop on traffic speed under heterogeneous condition for variable road way by considering all the parameters is essential for the planner to take some policy decisions in establishing the kerb side bus stop in urban areas. The present study is an attempt to fulfil this need.

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III. Objectives of the Study

The study is aimed to evaluate the impact of kerb side bus stop on traffic speed under mixed traffic condition and its reduction at each selected kerb side bus stop, in order to correlate the reduction in speed with the reduction in capacity. The broad objectives of the study are as follows:

To evaluate the effective road width and capacity of the road at selected kerb side bus stop locations in Addis Ababa city under various roadway and traffic conditions.

To estimate the variation of traffic speed for through traffic due to the presence of kerb side bus stop and to develop Regression Modals for analysing the reduction of speed at kerb side bus stop by considering the influencing parameters.

IV. Review of Literature

The various researchers carried out earlier in the fields related to the present study are reviewed and presented. More emphasis is placed on the research carried on speed-flow relationship, capacity and level of service, influence of bus stop on traffic flow characteristics. (Koshy & Arasan, August 1, 2005) Studied that the presence of bus stops on urban road links often leads to congestion and deterioration in the quality of traffic flow. In this study, a microscopic simulation model developed to replicate the flow of heterogeneous traffic on midblock sections of urban roads has been used to analyse the influence of bus stops on traffic flow.

Similarly, the study was conducted by (Bansal, et al., 2014) quantified the impact of bus-stops on the speed of motorized vehicles in the heterogeneous traffic conditions. The uniqueness of the research is featured through a study of a wide range of real world data collected during different days and times of a day by travelling in various vehicle classes (car, three wheelers, and two wheelers) on typical urban arterial roads. The presence of friction generators such as bus-stops, intersections, petrol pumps and pedestrian crossings, etc. significantly influences the speed of traffic stream.

(Zhang, et al., November 15, 2014) evaluated how different types of bus stops influence the operation of bicycles, vehicles, and buses. Four types of stops were considered according to the geometric feature and lane arrangement. Suggestions regarding the design of bus stops were discussed according to the delay of bicycles, vehicles, and buses produced at each stop type. Based on the traffic flow data collected from four types of bus stops, the bicycle speeds and vehicles speeds in the situations with buses at the stop and without any buses were evaluated and compared. The average bicycle speed was reduced by 1.06 km/h to 2.79 km/h near the bus stops. The average vehicle speed was reduced by 2.19 km/h to 6.82 km/h. The bus stopping time and leaving time were also evaluated for different bus stops.

(Mcknight, et al., October 2003) Quantified the impact of traffic congestion on bus operations and costs to Transit, and to forecast the future impacts of congestion on operations and costs. As traffic volumes or congestion increase, traffic speeds decrease, as established in traffic engineering formulas and curves that show speed as a function of the traffic volume to capacity ratio. The travel time model was used to estimate the increment in bus vehicle hours due to the increase in traffic travel time over free flow time.

(Xiaobao, et al., 23 April 2013) Proposed a model for estimating car delays at bus stops under mixed traffic using probability theory and queuing theory. The roadway is divided to serve motorized and non-motorized traffic streams. Bus stops are located on the non-motorized lanes. When buses dwell at the stop, they block the bicycles. Tus, two conflict points between car stream and other traffic stream are identified. The first conflict point occurs as bicycles merge to the motorized lane to avoid waiting behind the stopping buses. The second occurs as buses merge back to the motorized lane. The average car delay is estimated as the sum of the average delay at these two conflict points and the delay resulting from following the slower bicycles that merged into the motorized lane.

(Ben-Edigbe & Mashrons, 1st August – 1st September, 2011) Aimed that at determining capacity loss and traffic shockwaves associated with bus stop locations along the carriageway lane of a single lane highway. Roadway capacity is a quantitative assessment of traffic stream properties. It is based on relationship between flow, speed and density. A bus stop is a designated place where buses stop for passengers to board or alight. Bus stops are normally positioned on the highway and the bays are either located on or off the road carriageway lane to reflect the level of usage. Findings showed significant differences in roadway capacities for the on and off street bus stops.

Through the research of road capacity impacted by the vehicle temporary parking on the motor lane in front of schools, it is drawn that the main factors affecting road capacity is stopping frequency and parking time. So the parking time distribution characteristics are fitted, and proved the parking time in line with the Poisson distribution. For the large impact of road parking to the spacing, speed and other traffic characteristics, and the close relation to the road capacity, the speed-capacity model under road parking is established (Wang, et al., 2013).The goodness of fit test is great and the model can well reflect the actual situation of the relationship between speed and capacity under the road parking influence.

(Tirachini, 1 October 2013) Re-examined that the problem of deciding the optimal spacing of bus stops in urban routes, by re-considering the method used to calculate the probability of stopping in low demand markets (e.g., outer suburbs) and by analysing the interplay between bus stop size, bus running speed, spacing and congestion in high demand markets. (Ibeas, et al., 27 October 2009) develops a bi-level optimization model for locating bus stops to minimize the social cost of the overall transport system. The work takes into account possible changes in demand due to different bus stop locations considering congestion on buses, interaction with private traffic, operational variables (fleet, frequency, operator budgets), and the socio demographic characteristics of each zone in the urban area.

(Fatima & Kumar, 2 June 2014) Examines that the impact of a new public bus transit system by applying a binary logit analysis for assessing the possible variation in modal shift behaviour. Traffic quality parameters, such as average speed, delay, congestion, travel time, and travel cost were modelled to investigate the impact of the new bus transit system. (Cui, et al., 19 October 2014) Results shows that the proposed model is capable of optimizing the locations of bus stops connecting subways near intersections and helpful to improve the level of passengers service and operational efficiency of public transportation. Unsuitable locations of bus stops which provide feeder transportation connecting subways near urban intersections usually lead to the low efficiency of public transport and level of passenger service.

(Chand, et al., Oct 17 – 18, 2014) Reviewed the literature on the effect of kerbside and bus bay stop on urban traffic characteristics. It has been observed that presence of a bus stop ominously reduces the stream speed and capacity of an urban road. (Zhao, et al., November 1, 2009) presented a simulation model for mixed traffic flow composed of buses, cars, and non-motorized vehicles. Our model is within a completely different framework from previous ones since it has taken the non-lane based behaviours of non-motorized vehicles into account.

V. Location of Study for Data Collection

At Addis Ababa, traffic modes are highly congested and there is maximum enforcement of speed limits. In this situation, flow patterns result in a natural optimization of road use due to self-organization by road users.

Table 1. Details of the selected three kerb side bus stop

No.	Bus Stop	Mid-block	Road width (m)
1	Mexico St.	Piassa Roads- Jemo Junction	9m
2	Kera St.	Mercato St. to Gofa-Camp Junction	8.5m
3	Saris St.	Megenagna Cross Roads- Bole Bulbula Junction	6.4m

Table 1 presents the traffic conditions at this selected corridor represent heterogeneous operating environments on typical urban streets. Five types of data set were collected from selected corridor: (a) Volume of the given vehicles (pcu/hr.) (b) Bus frequency (c) bus dwell time(s) (d) effective road width (m) (e) % of speed reduction. This study principally focuses on the effects of bus-stops on the speed of other modes of vehicle under mixed traffic condition and buses are designated actually to stop at bus-stops for requirement for boarding and alighting. Therefore, buses affect the speed of vehicle because of they stop at their bus stop position. For the present study, three Kerb side bus stop locations having different traffic conditions and road widths ranging from 4 m to 10 m, in Addis Ababa are considered. All the study locations selected are in the mid blocks of major corridors in Addis Ababa city with heavy traffic movements both in peak and non- peak hours. These mid blocks are divided roads and there is no pedestrian crossing and negligible on street parking at and nearby the bus stops selected for the study.

VI. Data Collection and Survey Method

In the present study, different traffic surveys are conducted at each selected kerb side bus stop location to collect the traffic data such as classified traffic volume, speed of vehicles at and away from the bus stop, bus frequency, bus dwell time, approach road width and effective road width. The data is collected at each sections at and away from bus stop, during peak and non-peak hours with an interval of 15 minutes duration. The main task of the research was to model % of speed reduction rates in terms of volume, bus frequency, bus dwell time, effective road width. The dependent variable was the bus speed profile (kilometers per hour) of one bus trip on a given segment of route. The primary explanatory variable was a measure of traffic volume, expressed in the same form as for the bus speed profile rate for the same route segment. The following methodology is adopted for the data collection at each selected at and away from bus stop location for different surveys. All the surveys at each location are carried out simultaneously so as to full fill the objective of developing relationships between different parameters develop the correlation among them.

1. Traffic Volume Studies:

Classified traffic volume counts are carried out at the selected bus stop locations by manual method, the volume of the traffic is counted by using persons involved. They are called as Enumerators. However, according to the initial methodology, all types of data's were collected using Enumerators, fixer, stop watch and tally sheet format which shows their position and locations of all types the variables.

Figure 1 shows sections adopted for volume study at a typical bus stop required to count the traffic data in a particular mid- block of a corridor. In that case, a base line is to be drawn at the selected mid- block location and the enumerators will stand nearer to the base line. At two different stations taken, in which Station 1 is taken at some distance away from the bus stop on the upstream side, where the vehicles are not affected by the presence of kerb side bus stop and Station 2 is taken exactly at the bus stop, where there is a definite impact on traffic flow due to its presence. The station 1 is selected after careful observation of traffic throughout the day and after ensuring that the stoppages of buses at the bus stop do not affect the speeds of vehicles at that station. Later the enumerators have to record the occurrence of vehicles in the appropriate slot in the prepared volume data sheet.

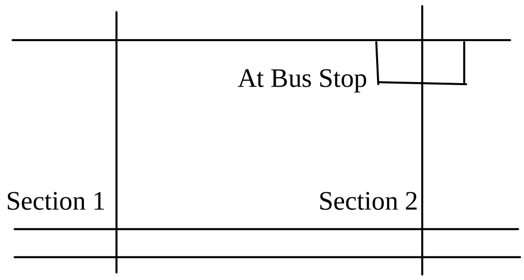

Figure 1. Sections adopted for Volume Study

2. Traffic Speed Studies:

Study is conducted by measuring the entry and exit timings directly at the selected location. The traffic speed is measured

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at each kerb side bus stop location in terms of Time mean speed by using direct timing procedure method.

The space mean speed is then calculated from the time mean speed by using the formula:

$$S = \frac{(3.6 * d * n)}{\sum t} \quad (1)$$

Where
S = Space Mean Speed (SMS)
d = distance between two sections considered
n = number of samples taken
Σt = sum of the time taken for the selected samples

Figure 2 shows sections adopted for speed study at a typical bus stop required to measure the traffic entry and exit timings directly in a particular mid- block of a corridor. Two base lines across the given road are to be marked for the purpose of study. The distance between base line 1 and base line 2 should preferably limited to 30 meter. For this, two different sections are considered. Section 1 is taken at some distance away from the bus stop, in which the speeds of vehicles are not affected by the presence of kerb side bus stop as mentioned in earlier article. Section 2 is taken such that the bus stop falls within the section almost at the Center so that the effect of stopped buses on speeds can be captured. Knowing the distance between the two base lines and journey time, the speed of individual vehicle can be calculated by taking Speed is equal to Distance/ Time. Data collecting process taken on: at bus stop and away from bus stop on the three kerb side bus stops.

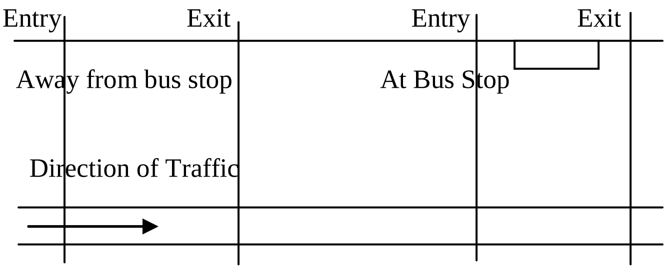

Figure 2. Sections adopted for Speed study.

3. Effective Road Width (ERW):

In the present study, a parameter called Effective Road Width is used to indicate the available carriageway width for traffic in meters, whenever a bus, stops on the road at a kerb side bus stop. In order to capture this effective road width, it is important to note where the bus stops and how much road width is lost due to bus stoppage. The methodology adopted for computing this effective road width is as follows: First of all, the clear carriageway width available at the bus stop is recorded when no bus is there at the bus stop. Longitudinal reference lines are marked on the road at 0.5 m intervals from the centre of carriageway towards bus stop up to 2.0 m from the kerb line.

The reasonable assumption here is that in any case, the stopped bus will not occupy road space beyond half of the carriageway available, as minimum carriageway considered in the study is 6.4 m. In each 15 minute interval, whenever a bus is stopped at the bus stop, the width lost due to its stoppage is recorded by noting down the reference point occupied by the body of the bus.

Figure 3 shows a road where carriageway available for one direction traffic is 9.0 m. So, reference lines are marked from 4.5 m from the kerb side up to 2.0 m towards kerb side. a hypothetical case where a bus is stopped and based on its position with respect to reference lines, it can be seen that it occupies a road width of 3.5 m. So, the effective road width available for the remaining traffic is 5.5 m as indicated in the figure. Thus for each bus stop, after the bus is stopped during a given 15 minute interval, the effective road width is calculated.

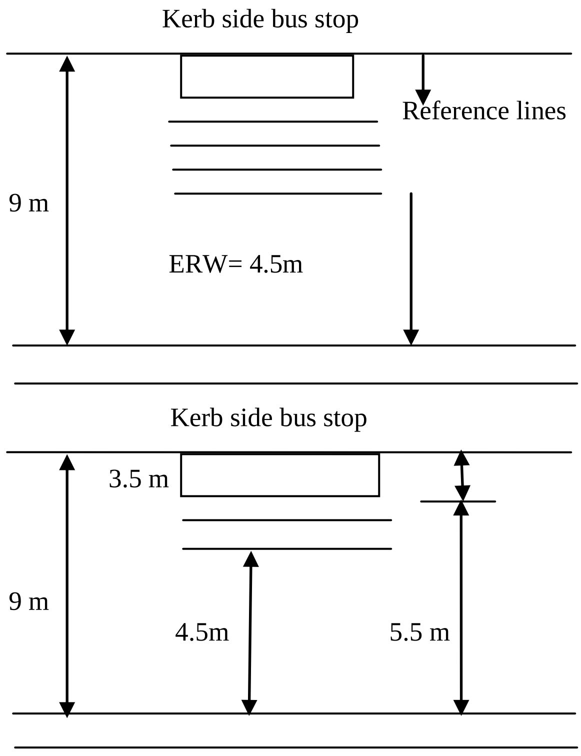

Figure 3. Sections adopted for Effective Road Width study.

4. Bus Frequency (BF):

Bus frequency is the rate at which bus occur over a particular period of time between consecutive services. Count the number of bus that comes every half hour, then the service by reading wait of a headway of 30 minutes. The number of bus repetition occur at the particular period of time for particular repetitive service express frequency.

5. Bus Dwell Time (BDT):

Time that a transit vehicle is stopped in a berth for the purposes of boarding or discharging passengers. Bus dwell time directly affects vehicle travel time, and thus the fleet size required to provide service based on scheduled headway is affected.

VII. Development of % of Speed Curves

The modal developed for the purpose of evaluating the reduction of speed is utilized to analyse the variation of speed reduction under different variations in the influencing parameters are presented in table 2.

Table 2. Cases for Developing % of Speed Curves

Case	Dependent Variable	Independent Variables
I	% of Speed Reduction	TV=500 to 4000 pcu/hr., BF=20 TO 80, BDT=30 to 120 sec, ERW= 4 m
II	% of Speed Reduction	TV=500 to 4000 pcu/hr., BF=20 to 80, BDT=30 to 120 sec, ERW= 6 m
III	% of Speed Reduction	TV=500 to 4000 pcu/hr., BF=20 to 80, BDT=30 to 120 sec, ERW= 8 m
IV	% of Speed Reduction	TV=500 to 4000 pcu/hr., BF=20 to 80, BDT=30 to 120 sec, ERW= 10 m

The graphs will be useful to analyse the variation of reduction of speed at the kerb side bus stop for various influencing parameters are elaborated in Figure 4 to Figure 7. The graphs are useful to generate certain guidelines for the erection of kerb side bus stop at the mid blocks in urban areas.

Case I:

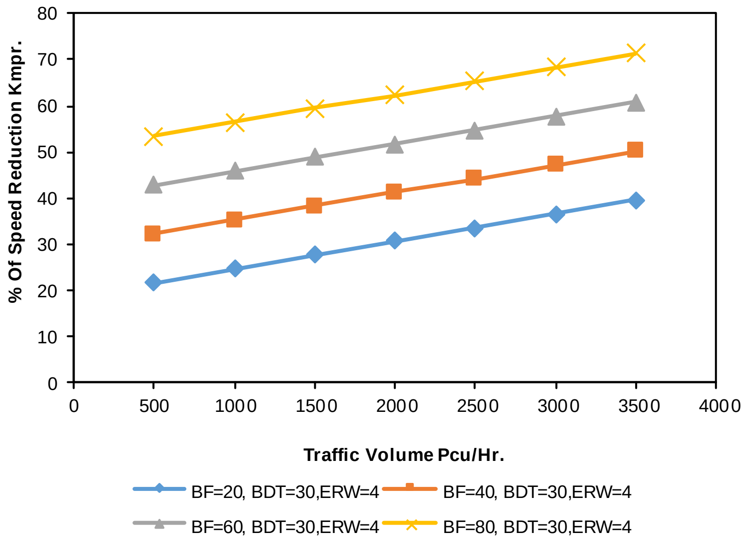

Figure 4. % SR, ERW=4, BDT=30, BF=20-80, V=500-4000.

Case II:

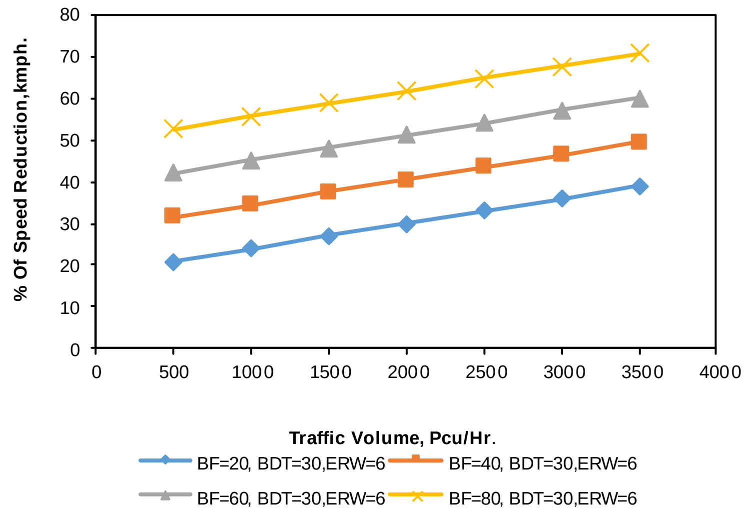

Figure 5. % SR, ERW=6, BDT=30, BF=20-80, V=500-1000.

Case III:

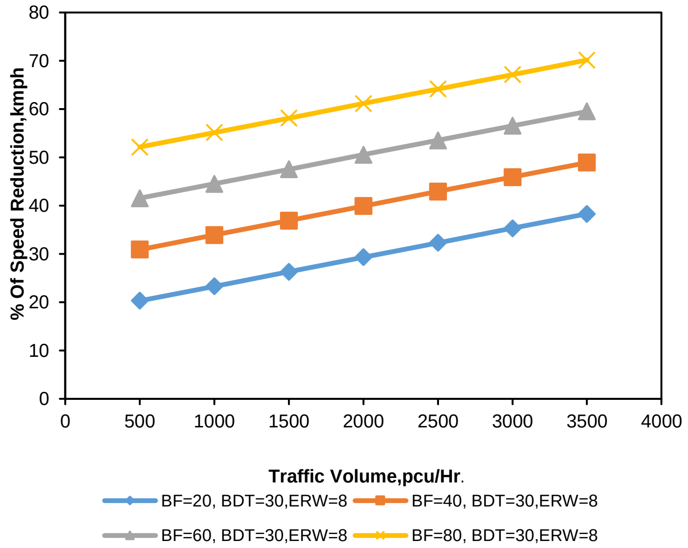

Figure 6. % SR, ERW=8, BDT=30, BF=20-80, V=500-1000

Case III:

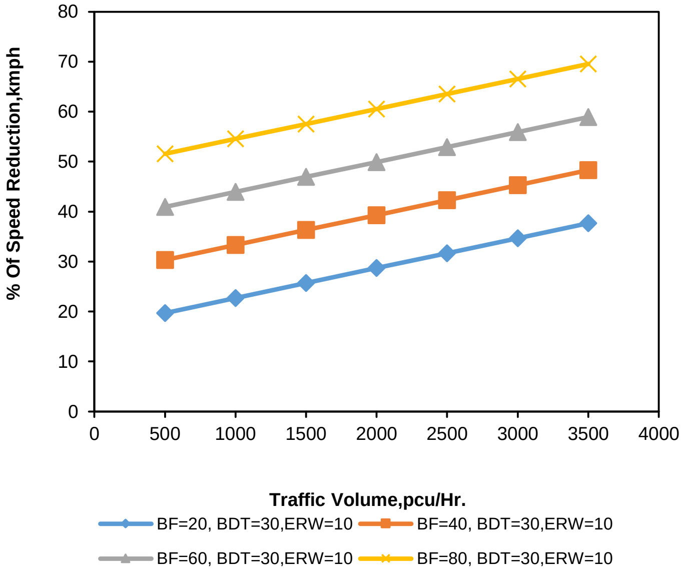

Figure 7: % SR, ERW=10, BDT=30, BF=20-80, V=500-1000

VIII. Summary and Conclusions

The presence of bus stops on urban road links often leads to congestion and deterioration in the quality of traffic flow. The evaluation of the speed of vehicles in a mixed traffic is a complex phenomenon which predominantly takes care of many influencing parameters that act either directly or indirectly on the traffic flow of the vehicles. The absence of lane discipline, the lack of road width due to encroachments by passengers, the presence of kerb side bus stops, uncontrolled side streets, street vendors, religious structures, the lack of enforcement measures, the lack of advanced technology, the lack of road space as per the vehicular growth and the lack of full-fledged management techniques are some of the reasons for the congested traffic flow in urban areas. In the study, an attempt is made to quantify the reduction in capacity of the mid-block due to the presence of kerb side bus stop.

Three kerb side bus stops in Addis Ababa of variable road widths and traffic characteristics are considered. Traffic data such as traffic volume, speed and effective road widths are collected at and away from each bus stop for a period of 12 hours in a day covering both peak hours and non-peak hours. The data is collected for every 15 minutes consecutive interval from 6 A.M. to 8 P.M. Multiple Linear regression model was developed to quantify the impact of kerb side bus stop on the speeds of other modes of vehicles under heterogeneous traffic conditions at selected midblock sections of urban roads. The width of the road at each of the bus stop is also measured. The developed modal was used for the purpose of analysis to observe the variation of speed reduction for various influencing parameters. % of Speed Reduction scattered graphs are plotted by considering at and away from each kerb side bus stop by taking volume of Traffic, bus frequency, bus dwell time and effective road width.

The % of speed reduction at and away from each bus stop is evaluated from the graphs at each kerb side bus stop is then evaluated. It is observed from the estimated % of speed reduction values that the reduction in speed at each section is not only in accordance with the reduction in the road width alone, but it is due to the reduction in the volume, dwell time, bus frequency and effective road widths at the respective bus stops which is found to vary based on various influencing parameters that are considered in the present study.

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