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Impact of Curbside Bus-stop on Roadway Capacity in Urban Roads: Comparative Assessment of Different Methods in context of Nepal

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Abstract

Curbside bus stops is one of the common features in urban environment targeted to public transportation users, but some time leads to reduction of capacity; hence causing traffic congestion. Hence it is utmost necessary to identify the impact of curbside bus stops on roadway capacity in urban roads. The primary data of volume, speed, density and other have been collected for one pilot corridor along urban area. As there is not specific standard for assessment of roadway capacity and hence many methods are being used in national context. This study tries to explore the impact of capacity reduction at bus stop location using Indonesian Highway Capacity Method (IHCM), Indian Highway Capacity Method (Indo HCM) and macroscopic traffic flow model.

Keywords: *Curbside Bus Stop, Capacity, Greenshield Model, Indo HCM, IHCM,*

1. Introduction

Urban areas worldwide face significant challenges in managing transportation systems amidst rapid urbanization and increasing motorization. Traffic congestion, inefficiencies in public transportation, and unregulated infrastructure often lead to decreased mobility, increased travel times, and environmental concerns. One pressing issue within urban transportation systems is the lack of proper planning and regulation for bus stops. Poorly designed or unregulated bus stops disrupt traffic flow, reduce roadway capacity, and create bottlenecks, particularly in densely populated areas. These challenges are exacerbated in rapidly growing cities, where increasing vehicle numbers and inadequate infrastructure planning collide, leading to severe mobility issues.

Chipledhunga, a bustling commercial and industrial hub in Pokhara City, is a critical node in the urban transportation network but faces significant traffic congestion due to unregulated curbside bus stops. Curbside bus stops, which lack dedicated space for buses to pull out of the traffic stream, cause disruptions by reducing the effective roadway width. The problem is compounded by Pokhara's rapid urbanization and motorization, with vehicle registrations in the region increasing annually by over 20,000(DoTM, 2018). Studies indicate that such disruptions at urban bus stops are a major factor in traffic inefficiencies, leading to reduced speeds, increased delays, and a notable reduction in road capacity. The absence of planned infrastructure forces buses to halt directly on the roadway, causing a ripple effect on surrounding traffic. Previous studies, such as those by(Koshy & Arasan, 2005), found that curbside bus stops can reduce traffic speeds by up to 25% under heterogeneous conditions. Similarly, research by(Khatawkar and Kumar, 2015) highlighted a 10–20% reduction in road capacity near urban bus stops in India, emphasizing the significant impact of unregulated bus operations. The Indonesian Highway Capacity Manual (IHCM, 1993) supports these findings, suggesting that such disruptions alter the flow-density relationship, leading to bottlenecks and capacity loss.

There is no unitary and context-based standard of capacity estimation in the perspective of the heterogeneous nature of traffic particularly in urban contexts where the curbside bus stops remain unregulated. International models cannot usually be used without calibration to the local situation because traffic organization, pedestrian behavior and road/street infrastructure are different around the world. The study will fill this gap by analyzing the effects of a curbside bus stop on road capacity in Pokhara and comparing three ways to estimate this effect (the Indo-HCM, the IHCM and the Greenshield model), which will help to see to which extent they can be applied in the Nepali case.

2. Objective

This study explores the impact of the Chipledhunga curbside bus stop on urban road capacity and traffic dynamics in Pokhara City. It aims to quantify capacity reductions at curbside compared to other side (non-curbside direction) through different models as well as analyze speed variations in these areas. By collecting and analyzing comprehensive data—such as traffic volume, speed, and density; the research seeks to uncover the specific challenges posed by curbside stops.

3. Literature Review

The bus stops of public transportation buses are where people are supposed to get on and off from them. There is significant effect on traffic flow from various kinds of bus stops, like curbside stops, bus bays, queue jumpers, and nubs. (Chand & Chandra, 2014). The number and type of bus stops provided on a road significantly influences the flow characteristics of traffic on the road (Koshy & Arasan, 2005b). The curbside bus stop is the most common type of bus stop all over the world (Bian et al., 2015). They are often built to support the operation of the transit system(Li et al., 2020). In Nepal, the primary causes of road accidents are factors such as heavy traffic flows and speed (Tiwari & Luitel, 2023). Curbside bus stops are those located on-street to the side of the carriageway. They are constructed on heavily trafficked urban roads where there is insufficient space for a segregated bus bay (Chand & Chandra, 2017). Traffic characteristics of a roadway, such as speed, are significantly influenced by bus stops (Patkar & Dhamaniya, 2020).

The capacity of urban roads must be separated into several segments if the road characteristics change significantly. Changes in carriageway and shoulder width (up to 15%), road type, visibility, type of road alignment, and exits from urban or semi-urban areas, even if the geometric or other characteristics do not change.(Civil Engineering Department, Universitas Pancasila, 12640, Indonesia et al., 2025). The traffic flow shows a strong temporal and spatial correlation and is susceptible to weather, seasons, holidays, and other external factors.(Gao et al., 2024)

A highway facility's capacity is the maximum hourly flow rate that, given the current traffic and road conditions, people or cars could reasonably be expected to travel through a certain point or uniform section of a lane or roadway in a particular period of time (Yadav et al., 2014). The capacity of urban roads is mainly dependent on the ratio between duration of a green phase and cycle length at the signalized intersection on the end of the link (Dhamaniya & Chandra, 2017). Capacity estimation is fundamental for design, planning, operation, and layout of road network sections. There are different direct and indirect empirical methods for capacity estimation (Jain et al., 2020). The characteristics of traffic flow can be modeled to determine the nature of traffic, which aids in choosing the appropriate control system and making other transportation planning decisions. There are basically two classifications of these models which includes macroscopic and microscopic model (Bello et al., 2024). Microscopic simulation techniques can yield realistic estimates of speed-flow relationships because such models consider each vehicle movement on a roadway and hence the lane change behavior and vehicle interactions in mixed traffic can be better described (Arun et al., 2013). They contain abundant autonomous parameters to illustrate the features of behavior of drivers, traffic flow, and traffic regulatory processes (Ghosh et al., 2020). Microscopic traffic simulation models possess the flexibility to represent rich spatial and temporal demand patterns, model complex driving behavior phenomena and the interactions between individual vehicles, mimic drivers' travel behavior decisions such as route choice and response to information, and simulate the operations of traffic management strategies, technologies, and infrastructure(Balakrishna et al., 2007). Some examples of these models are the Greenshield, the Greenberg logarithmic, and the Underwood exponential. To explain the relationship between traffic characteristics, namely volume, speed, and density, the Greenshield Method is used which uses a linear approach (Wijanarko, 2023). This model has been widely used in traffic flow analysis and capacity estimation studies (Bello et al., 2024).

Although, many studies have been carried out on the effect of bus stop on traffic flow, majority of the studies are in homogeneous traffic environments, or they have been conducted in controlled conditions. Currently available models like HCM 2010 are developed considering developed nations and they do not take into consideration the high level of variability in type of vehicles, poor lane discipline and high level of pedestrian disruption obsessive in Nepal. Even though adjustment factors to such conditions are given in the IHCM, Indo-HCM, they have not been critically assessed or locally developed. There are no earlier studies conducted in Nepal comparing such models and exploring their appropriateness to unregulated curbside bus stops. The current study fills that gap by comparing and implementing these models to mixed-traffic scenario in Pokhara, Nepal.

Greenshield's model of traffic flow, which defines a linear relationship between speed and density, has been extensively used to study the impact of roadside disruptions on traffic capacity(Greenshields, 1935). This model is considered as the powerful tool in the field of traffic flow modeling due to its simplicity and reasonable goodness of fit found in context of Nepal (Tiwari and Marsini, 2014). Greenshield was able to develop a model of uninterrupted traffic flow that predicts and explains the trends that are observed in real traffic flows in another case of Baneshwor, Kathmandu, Nepal(Gautam et al., 2023). However, the Indian Highway Capacity Manual (INDO-HCM, 2017) offers an advanced perspective tailored to India's heterogeneous traffic conditions which is similar to the context of Nepal. Incorporating INDO-HCM into the study provides additional insights into traffic capacity and flow under conditions like those observed in Pokhara. The recent study on Srijana Chowk suggests that Indonesian Highway Capacity Manual is relevant in estimating traffic flow characteristics in context of Nepal yielding good significant goodness of fit of the developed model and being comparable with other macroscopic traffic flow model. (Thapa et al., 2024). The formula used for the calculation of capacity of the road has been taken from Indonesian Highway Capacity Manual (IHCM, 1993). The value of base capacity and coefficients has been taken from (IHCM, 1993) tables. All the adjustment factors are taken based on criteria as per IHCM 1993

$$C = Co*Fw*Fks*Fsd*Fsf*Fcs \quad ....(1)$$

Where, C = Capacity (PCU/hr.)

Co = Base Capacity (PCU/hr.)
Fw = Carriageway width adjustment factor
Fks = Kerb and shoulder adjustment factor
Fsf = Side Friction adjustment factor
Fsd = Directional split adjustment factor
Fcs = City size adjustment factor

Similarly, The formula used for the calculation of road capacity has been taken from the Indian Highway Capacity Manual (INDO-HCM, 2017).The base capacity and coefficients values are sourced from INDO-HCM tables.

C = Co * Rw * Tc * Sf * Fi ....(2)

Where,

C = Capacity (PCU/hr)
Co = Base Capacity (PCU/hr)
Rw = Road Width Adjustment Factor
Tc = Traffic Composition Factor
Sf = Side Friction Factor
Fi = Flow Interaction Factor

4. Materials and Methods

The study employed a quantitative research approach to analyse traffic flow and geometric characteristics at Chipledhunga's curbside bus stop in Pokhara City. Data were collected in April 2024 using both video and manual methods, with cameras positioned at two stations to record traffic during peak and off-peak hours over two working days. Classified traffic counts were conducted at 15-minute intervals, capturing a sample of 15% for motorcycles and 100% for other vehicles. Geometric measurements of the bus stop included details such as carriageway width, shoulder width, and footpath width. Data were recorded in Microsoft Excel and converted to Passenger Car Units (PCU), with speed and density computed based on the recorded metrics.

To model the speed-density relationship, Greenshield's model was applied, using 12 hours of recorded data—9 hours for calibration and 3 hours for validation. The model was calibrated using Microsoft Excel and the Solver add-in, which identified a linear speed-density relationship. Speed and density values were used to estimate free-flow speed, jam density, and capacity for both sides of the bus stop. These calculations helped determine the performance of traffic flow at the location.

Validation of the model was performed through statistical tests, including ANOVA, t-tests, and p-values, which confirmed significant capacity reductions. The calibrated Greenshield's model enabled accurate capacity estimation for the bus stop, and the model's results were compared with actual capacity values. These findings provided insights into the effectiveness of the model and its applicability in assessing traffic flow at the curbside bus stop in Pokhara City.

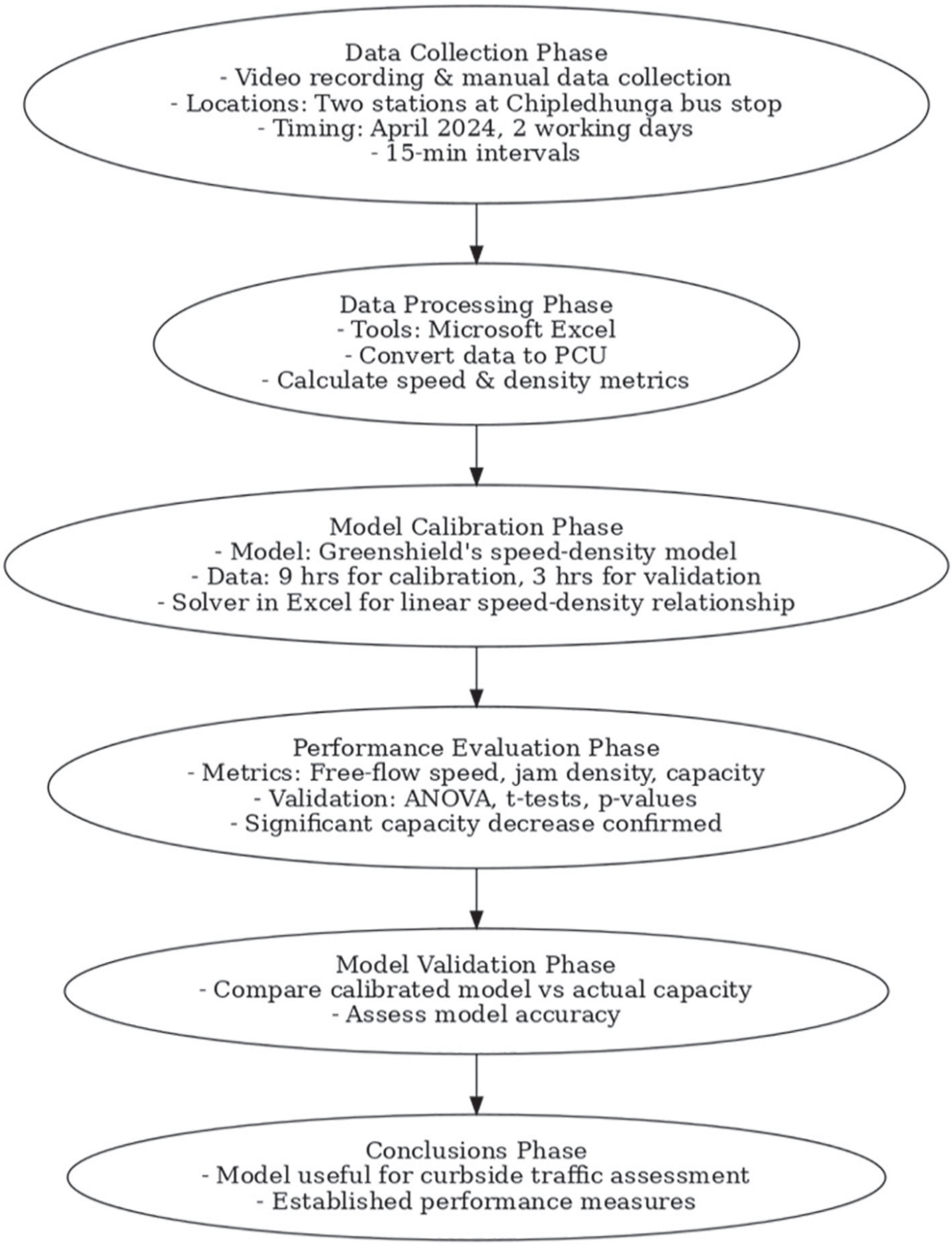

Figure 1: Methodological Flow Chart

5. Results and Discussion

5.1 Speed Analysis

The average space mean speed (SMS) for individual vehicle types was computed for both at both curbside bus stop and non-curbside bus stop direction. The results are presented in Table 1 and Table 2.

Table 1: Space Mean Speeds (SMS) at Chipledhunga

Section	Bike (Kmph)	Car (Kmph)	Taxi (Kmph)	Jeep (Kmph)	Utility (Kmph)	Truck (Kmph)
At Bus Stop	33.2	31.2	31.9	24.0	23.3	18.7
Non- Curbside direction	34.7	32.5	32.4	24.6	23.7	19.3

Table 2: Total Stratified Average Speeds at Chipledhunga

Section	Average Speed (Kmph)	Speed Reduction (%)
At Curbside Bus Stop Direction	30.95 ± 1.02	6.55%
At non-curbside bus stop direction	33.12 ± 1.03	-

The average speed reduction in the direction of Chipledhunga bus stop was 6.55% compared to the other side (non-curbside direction). Bikes experienced a minor speed drop of 3.21%, while heavier vehicles such as trucks and utility vehicles showed significantly lower speeds due to the stop. This reduction indicates the influence of the curbside bus stop on vehicle speed and road efficiency.

52 Capacity Estimation

The capacity has been calculated using various methods including Indonesian Highway Capacity Manual, Indian Highway Capacity Method and commonly used Greenshield model.

5.2.1 IHCM-Based Capacity Calculation:

The capacity at Chipledhunga bus stop during peak hours was computed using the Indonesian Highway Capacity Manual (IHCM), incorporating relevant adjustment factors for pedestrian activity, infrastructure characteristics, and local conditions which includes the following:

- Walking Pedestrians: **25,** Crossing Pedestrians: **35**
- Carriageway Width Adjustment Factor: **0.86–0.9**
- City Size Adjustment Factor (Chipledhunga): **0.8**
- Fks (Kerb and Shoulder Width): **0.98**
- Side Friction Factor (Fsf): **0.86–0.9**
- Directional Split Adjustment Factor (Fsd): **0.99**

The resulting capacity for the curbside bus stop is:

$C=4000\times1.00\times0.98\times0.88\times0.99=2732$ PCU/hr

5.2.2 INDO-HCM-Based Capacity Calculation:

For comparison, the capacity was also estimated using the Indian Highway Capacity Manual (INDO-HCM), which accounts for side friction and flow interaction factors more explicitly in estimating pedestrian impact on capacity.

- Walking Pedestrians: **50,** Crossing Pedestrians: **75**
- Side Friction Factor (Sf): **0.85–0.90**
- Flow Interaction Factor (Fi): **0.90**

The INDO-HCM formula for capacity estimation for curbside bus stop is:

$C=4000\times1.00\times0.95\times0.90\times0.90=3078\,PCU/hr$

For the **non-curbside curbside**, with fewer pedestrian interactions, the capacity is:

$C=4000\times1.00\times0.95\times1.00\times1.00=3800\,PCU/hr$

The **IHCM** estimation yields a lower capacity (2732 PCU/hr) due to its more conservative assumptions about pedestrian interactions and infrastructure factors. The **INDO-HCM** approach provides higher capacity estimates yielding **3078 PCU/hr** at the direction of curbside and **3800 PCU/hr** in the non-curbside direction.

5.2.3 Capacity Calculation using Macroscopic Traffic Flow Model

Similarly, the capacity was also calculated using the Greenshields model due to its wider acceptability in context of Nepalese Roads. Hence the speed and density data collected was used to calibrate the equation for both curbside and non-curbside direction. Model calibration as per Greenshields at curb side and non-curb side bus stop direction is shown in the graph shown in Fig 2 and 3.

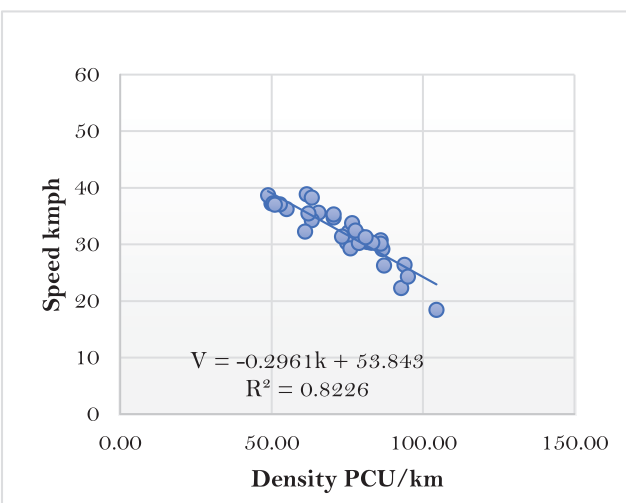

Figure 2: V-K curve at curbside direction

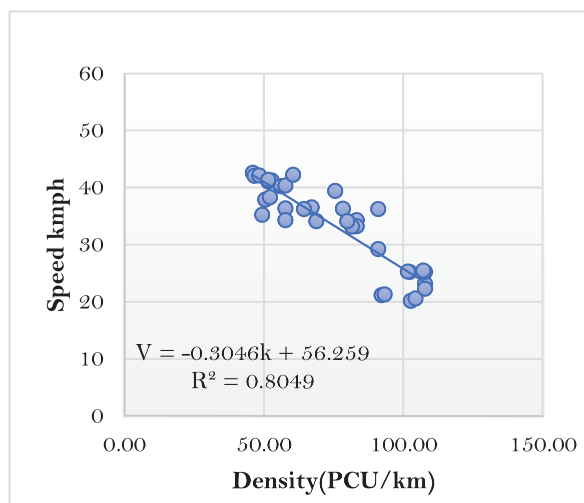

Figure 3: V-K curve at non-curbside direction

The calculation of capacity based on Greenshields model is shown in Table 3.

Table 3: Calibrated capacity

Section	Calibrated Equation	R^2	Free flow speed (kmph)	Calibrated Capacity (PCU/hr)
Curbside Direction	V= -0.2961k +53.843	0.82	53.8	2448
Non-curbside direction	V= -0.3046k +56.259	0.81	56.3	2598

The calibrated capacity values closely align with the actual capacity measurements, with variations remaining within 3%. The results of the ANOVA test yielded a p-value of 0.488 for a two-tailed analysis, exceeding the significance threshold (α = 0.05), and the t-statistic was found to be lower than the critical t-value. Consequently, no statistically significant difference was detected between the calculated and observed capacities in the study area. This is summarized as below

Table 4: Statistical Significance analysis

Location	Pearson corelation	df	tstat	P(T<=t) one-tail	t Critical one-tail	P(T<=t) two-tail	t Critical two-tail
At curbside bus stop	0.86	11	-1.450	0.087	1.796	0.175	2.201
Non curbside Direction	0.83	11	0.826	0.213	1.796	0.573	2.201

5.3 Capacity Reduction Calculation

The capacity reduction was estimated to be 7.92% using Greenshield's model, 11.97% using IHCM and 9.95% using INDO-HCM as detailed in Table 5 below. These results provide a basis for extending the study to a range of road and traffic conditions, enabling the formulation of comprehensive guidelines and warrants for the implementation of bus laybys in similar scenarios.

Table 5: Capacity Reduction comparison

At curbside bus stop Capacity (PCU/hr)	Non-curbside bus stop Capacity (PCU/hr)	Theoretical capacity (PCU/ hr) as per table 4	Capacity reduction (%) as per Greenshield's Model	Capacity reduction (%) as per IHCM	Capacity reduction (%) as per INDO-HCM
2405	2612	2732	5.8	11.97	9.95

6. Conclusions

The assessment of impact of curbside bus stop revealed significant impacts on traffic capacity, flow, and speed, highlighting the challenges posed by curbside bus operations. The capacity at the curbside was estimated at 2405 PCU/hr, while in the non-curbside direction exhibited a slightly higher capacity of 2612 PCU/hr using Greenshield's model. The capacity reduction was found to be 5.8% using Greenshield's model,11.97% using the Indonesian Highway Capacity Manual (IHCM) and 9.95% using Indian Highway Capacity Manual (INDO-HCM), indicating that bus stops substantially disrupt traffic flow.

The stream speeds at Chipledhunga were notably affected by the curbside bus stop. The average speed for motorcycles and cars on the curbside ranged between 29.1 km/h and 25.2 km/h, respectively, while on the non-curbside direction, speeds were higher, ranging from 30.5 km/h to 26 km/h. This resulted in a speed reduction of 6.55%, which can be attributed to the interference caused by the bus stop, where vehicles are forced to slow down due to bus activities and traffic congestion.The analysis is based on the factor developed by Indonesian Highway Capacity Manual or Indo HCM; it is recommended for further study to propose or calculate national context specific factors for Nepal.

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