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Determination of Passenger Car Unit and Capacity Loss at Curve Section of Two-Lane Undivided Highway: A Case Study of Balkhu-Chovar-Dakshinkali Road Section

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Abstract

Passenger Car Units (PCU) serve as a crucial metric in assessing the impact of different vehicle types on traffic flow, particularly in heterogeneous, non-lane-based traffic conditions prevalent on Nepal's two-lane undivided highways. Factors such as lane width, horizontal alignment, gradient, lateral clearance, and shoulder conditions significantly influence PCU values and roadway capacity. However, the specific effect of horizontal curve radius on PCU estimation and capacity loss remains largely unexplored in Nepalese road conditions.

This study investigates the influence of horizontal curve radius on PCU values and roadway capacity along the Balkhu-Chovar-Dakshinkali highway using videographic traffic surveys. Speed-flow-density relationships were established using Greenshield's model, and the dynamic PCU method was applied to estimate PCU values based on speed variations and projected vehicle areas. The findings indicate that PCU values increase with curve radius, with heavy vehicles, such as buses and trucks, exhibiting more significant changes than light vehicles. Specifically, PCU values for buses ranged from 5.2986 to 5.4333, and for trucks from 3.3743 to 3.4450, as the curve radius expanded from 32m to 151m.

Additionally, capacity loss was found to decrease as the curve radius increased, with a 25.27% reduction at a 32m radius and 7.92% at a 151m radius. The maximum roadway capacity at the Chovar straight section was found to be 1451 PCU/hr per lane, which is lower than the 1600 PCU/hr per lane suggested by the Indian Highway Capacity Manual (HCM) for hilly terrain. These results emphasize the significant impact of horizontal curvature on heavy vehicles and highlight the necessity for curve-specific PCU estimation and geometric design improvements to minimize capacity loss and optimize roadway performance on hilly terrain highways.

Keywords: Traffic composition; Speed; Passenger Car Units; Volume; PCU; Capacity

1. Introduction

Two-lane, two-way highways play a crucial role in transportation networks across many countries, including Nepal, where they serve as vital links between urban centers and rural regions. These roads face unique operational challenges due to heterogeneous traffic conditions, where vehicles of varying sizes, speeds, and maneuverability share the same carriageway without strict lane discipline (Chandra & Kumar, 1996). Factors such as lane width, shoulder width, horizontal alignment, and gradient further influence vehicle behavior and roadway capacity. The complex nature of mixed traffic movement on these highways makes understanding traffic flow characteristics, capacity estimation, and appropriate road design essential for improving safety and operational efficiency.

Passenger Car Unit (PCU) factors provide a standardized metric to quantify the impact of different vehicle types on roadway capacity. They allow for the conversion of mixed traffic flows into a common unit, enabling accurate traffic flow analysis, capacity estimation, and roadway design. PCU factors are relevant in both homogeneous and heterogeneous traffic conditions, but they are particularly critical in developing countries like Nepal, where non-lane-based traffic behavior dominates. In contrast to homogeneous traffic systems, where vehicles follow designated lanes with minimal interaction, Nepalese highways accommodate diverse vehicle types, including two-wheelers, cars, light commercial vehicles (LCVs), buses, and heavy trucks, all operating in a shared space with frequent overtaking and lateral movements. Consequently, the estimation of PCU values is essential for traffic planning, congestion management, and future road expansion strategies in such environments.

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Traditional capacity estimation models, such as those outlined in the Highway Capacity Manual (HCM, 2000) and the Indian Roads Congress (IRC, 2017), are primarily designed for lane-disciplined, homogeneous traffic and rely on Level of Service (LOS) criteria to determine roadway width, lane count, and intersection design. However, these methodologies often fail to accurately represent heterogeneous traffic conditions, where speed variations, overtaking behavior, and vehicle interactions significantly influence road performance. To address this challenge, PCU-based approaches have been introduced to adjust capacity calculations for mixed traffic, providing a more effective tool for highway planning and traffic engineering in Nepal's road network.

The Balkhu-Chovar-Dakshinkali highway is a two-lane undivided road that serves as a critical transportation corridor connecting Kathmandu to Nepal's eastern Terai region. Over the past decade, traffic volume on this road has nearly doubled, with Average Annual Daily Traffic (AADT) increasing from 5,781 to 11,162 vehicles (DoR, 2023). The presence of narrow horizontal curves along the highway significantly impacts traffic flow and capacity, particularly for heavy vehicles, resulting in increased congestion, longer travel times, and frequent traffic queues. Additionally, the curved sections pose safety risks due to limited visibility and the effect of centrifugal forces on vehicle stability, further complicating roadway operations.

Understanding PCU values and capacity loss on curved road sections is essential for improving traffic management, road safety, and highway design. The insights gained from this study will inform whether geometric modifications such as curve widening, additional lanes, or other engineering interventions are necessary to enhance road efficiency. Furthermore, the Balkhu-Chovar-Dakshinkali highway has the potential to serve as an alternative route to reduce congestion on the Nagdhunga-Naubise-Muglin-Narayangarh road, a heavily trafficked national highway. Accurate PCU estimation and capacity analysis on this route will contribute to evidence-based decision-making for Nepal's growing transportation infrastructure needs.

2. Objective

This research aims to determine the Passenger Car Unit (PCU), capacity, and capacity loss on straight and curved sections of a two-lane undivided highway, focusing on the Balkhu-Chovar-Dakshinkali road. It seeks to calculate the PCU for various vehicle categories and examine how PCU values relate to the radius of curves. Additionally, the study explores the correlation between capacity loss and curve radius, providing insights for improving road design and traffic management in hilly terrain.

3. Literature Review

Chandra and Kumar (1996) developed a speed-based approach to estimate PCU values by considering vehicle area rather than just length in mixed traffic conditions. Data were collected from ten two-lane road sections in India, and the speed-area method was applied to compute PCU values based on observed speed differentials and carriageway width. Hashim (2011) examined the effect of horizontal alignment and lane width on PCU values in Egypt using videographic traffic surveys and regression models. It was found that PCU values increased as curve radius decreased, particularly for heavy vehicles.

Shalkamy et al. (2015) investigated the effect of horizontal curvature on PCU values for different vehicle categories on two-lane highways in Egypt, using statistical modeling and regression analysis. The study indicated that capacity increases with both carriageway width and curve radius, with capacity loss diminishing for wider curves. By applying the model proposed by Chandra et al. (1995), a linear increase in PCU values with increasing curve radius was observed across all vehicle types. Regression models were developed to quantify this relationship, showing that buses had higher PCU values than minibuses and light trucks, while PCU values for light vehicles remained relatively constant. The relationships were defined as

$$PCU=6.032+0.000832r \text{ for single-unit and trailer trucks} \tag{1}$$

$$PCU=4.244+0.000376r \text{ for buses} \tag{2}$$

$$PCU=2.132+0.000430r \text{ for light trucks} \tag{3}$$

$$PCU=1.229+0.000041r \text{ for minibuses} \tag{4}$$

$$PCU=0.177754+0.000025r \text{ for two-wheelers} \tag{5}$$

where r represents the curve radius in meters.

It was also observed that heavier vehicles experienced greater PCU variations due to maneuverability constraints and speed fluctuations, while lighter vehicles were less affected by curvature.

Malla (2023) applied the dynamic PCU method on Nepalese two-lane highways, utilizing videographic surveys to collect speed, density, and traffic flow data. PCU values were estimated using Chandra's speed-area methodology, while capacity was determined through Greenshield's speed-density model. Biswas (2021) conducted a review of static and dynamic PCU estimation methods, highlighting that PCU values are highly sensitive to regional variations in traffic composition and roadway conditions.

Bomzon et al. (2021) applied the speed-area method in East Sikkim and found that minimal effects of traffic conditions on PCU values existed, reinforcing the need for localized PCU adaptation. Tullu et al. (2016) used VISSIM simulation for urban roads in Quetta, demonstrating that PCU values fluctuate with traffic volume, reinforcing the need for real-time adaptive PCU models. Shrestha (2013) modeled PCU values for saturation flow and delays at intersections in Kathmandu using multiple regression analysis. It was observed that PCU values vary significantly based on intersection type, traffic density, and driver behavior, supporting the argument that a single PCU value is not universally applicable.

Gibreel et al. (1999) conducted a three-dimensional geometric analysis to investigate the impact of road design consistency on capacity. It was revealed that a consistency factor accounts for geometric errors affecting roadway capacity, as actual service flow rates were found to be lower than theoretical predictions.

Chandra and Kumar (2003) examined Indian two-lane road segments and concluded that PCU values decrease as carriageway width increases. Yang and Zhang (2005) carried out a study on highway capacity in Beijing using traffic simulation models and determined that capacity decreases as the number of lanes increases, presenting a different trend than in India. Ben-Edigbe and Ferguson (2005) investigated road conditions in Nigeria, showing that pavement distress significantly increases PCU values by reducing vehicle speeds and disrupting traffic flow stability. Kim (2010) applied simulation-based models to analyze highway capacity in Japan, finding that PCU values vary dynamically with congestion levels, suggesting that fixed PCU values may not be appropriate for urban environments.

Banskota (2018) and Malla (2023) reported that PCU values in Nepal differ from international standards. It was concluded that discrepancies exist due to variations in road width, vehicle dimensions, and driver behavior. These findings reinforced the need for localized PCU estimation models rather than relying on standardized values from other countries. Chandra (2004) studied the factors affecting capacity on two-lane roads and determined that road roughness reduces vehicle free-flow speed and capacity, especially for passenger cars.

Hashim et al. (2011) revealed that capacity on rural two-lane roads in Egypt is influenced by lane width and curve radius, with capacity losses inversely related to curve radius.

This study builds upon previous research by investigating the effect of horizontal curve radius on PCU values and roadway capacity in Nepal’s hilly, mixed-traffic conditions. Unlike past studies that primarily focused on gradient effects, lane width, or intersections, this research specifically analyzes how curve radius influences PCU values for different vehicle types and capacity loss. The dynamic PCU method is employed using Chandra’s speed-area methodology, with data collected through videographic traffic surveys. PCU values are estimated for both straight and curved sections, while capacity estimation is performed using Greenshield’s speed-density model. A quantifiable relationship between PCU, capacity, and curve radius is established, contributing to localized PCU estimation models for Nepalese highways and assisting in capacity planning and roadway design improvements.

4. Methodology

To achieve the research objectives, a comprehensive methodology was developed, incorporating research design, data collection, and analysis. The study was conducted along a 15 km section of the Balkhu-Chovar-Dakshinkali road, which connected Kathmandu and Makwanpur District. The road carried approximately 11,162 vehicles per day (DoR, 2023) and was a two-lane undivided highway with a mix of straight and curved sections. After proper inspection, five study locations were selected to ensure uniformity in roadway conditions, minimizing the influence of external factors on PCU estimation and capacity analysis.

The study sections were situated on fairly level terrain, ensuring that gradient did not affect traffic flow or PCU values. The lane width at straight sections ranged between 6.3m and 6.4m, maintaining uniformity across different study locations. At curve sections, the lane width varied between 6.4m and 6.9m, ensuring consistency in roadway conditions for accurate analysis. The shoulder width was nearly uniform, ranging from 0.3m to 0.35m, paved on both sides.

The selected curve sections had varying radii between 32m and 151m, allowing for a comparative analysis of PCU values and capacity loss. Each curve section was paired with a corresponding straight section for reference. Intersections were avoided, ensuring uninterrupted flow for accurate speed and density data extraction. The geometric details of the study location are summarized in Table 1.

Table 1. Geometric details of the study locations

Section Name	Curve Radius (m)	Carriageway Width (Straight) (m)	Shoulder Width (Straight) (m)	Carriageway Width (Curve) (m)	Shoulder Width (Curve) (m)

Chovar Site 1	90	6.4	0.3 (Paved)	6.4	0.3 (Paved)
Mahadev Mandir Dakshinkali	68	6.3	0.3 (Paved)	6.9	0.3 (Paved)
Taudaha Site 1	32	6.3	0.35 (Paved)	6.7	0.3 (Paved)
Taudaha Site 2	104	6.3	0.3 (Paved)	6.7	0.3 (Paved)
Bhanjyang Dakshinkali	151	6.4	0.3 (Paved)	6.4	0.3 (Paved)

4.1 Data collection

The data collection period was carefully selected to capture representative traffic conditions. Videographic surveys were conducted during two peak periods: 8:30 AM – 11:00 AM and 3:30 PM – 6:00 PM. According to Dakshinkali police checkpost and (Shrestha, 2024) peak vehicle flow occurs between 9 AM to 11 AM and 4 PM to 5 PM. This scheduling ensured minimal external disruptions such as extreme weather or road construction. Data were collected between March 14 to March 20, 2024, providing a clear temporal reference for the study.

Two video cameras were strategically positioned at elevated points to capture traffic movement, focusing on the entry point of the straight and the exit point of the curve. Traffic data were collected in one direction only, from Dakshinkali to Balkhu, for five hours.

A traffic count was conducted by reviewing video footage during the identified peak hours. The recorded videos were used for classified traffic counts, capturing vehicle passage through the road section every 15 minutes. The speed of different categories of vehicles was determined by the trap length of the road and travel time. By recording the time, it took for a vehicle to travel a fixed distance of less than 90 meters, spot speed was measured (Mathew, 2019). The speed data collection followed the volume-proportionate sampling method, ensuring that the speed of each vehicle category (motorcycles, cars, LCVs, buses, and trucks) was recorded in proportion to their observed share in traffic composition. Traffic density was assessed by counting the number of vehicles within parallel traverse lines in the video playback.

Secondary data included vehicle dimensions sourced from the Nepal Automobile Survey (2016), which provided detailed information on the vehicles commonly used in Nepal. Traffic flow, speed, and density were calculated based on the field data collected. The mean stream speed of traffic flow was determined using the space mean speed technique. This method involved recording the entry and exit times of various vehicles along specific road sections and computing the space mean speed based on a trap length. To ensure precision, the time taken for a vehicle to traverse the trap length was measured to a precision of 0.01 seconds. For sampling purposes, an equal proportion of the total volume of vehicles in each class observed during a 15-minute interval was considered, following the methodology outlined by Tiwari and Marsani (2014).

4.2 PCU estimation

To estimate Passenger Car Units (PCU), the study adopted the dynamic PCU method based on Chandra's approach, which considers the influence of vehicle speed and projected area on traffic flow under heterogeneous, non-lane-based conditions. The PCU values were determined using the speed-area method, which is suitable for mixed traffic conditions where vehicles do not follow strict lane discipline (Bomzon et al., 2021).

The formula used for PCU calculation is given as follows (Chandra & Kumar, 1996):

$$PCU_i=(V_c/V_i)\times(A_i/A_c) \quad (6)$$

where,
PCU_i = Passenger Car Unit for vehicle type i,
V_c = Mean speed of a standard passenger car (km/h),
V_i = Mean speed of vehicle type i (km/h),
A_i = Projected rectangular area of vehicle type i (m²),
A_c= Projected rectangular area of a standard passenger car (m²).

Capacity analysis utilized the linear speed-density model, which provided optimal results under uninterrupted and heterogeneous traffic conditions (Gautam & Jain, 2018). Green shield's linear speed-density assumption further validated the analysis specific to Nepal's conditions (Thapa et al., 2024). The capacity for each study location was determined from the developed speed-flow curves using observed traffic data. The speed-density relationship follows Greenshield's model, Flow was determined by multiplying speed and density, and the maximum capacity was obtained using the relationship

$$q_{max}=U_f \times k_j/4 \quad (7)$$

where,
q_{max} = Maximum capacity (vehicles/hour)
U_f = Free-flow speed (km/h)
k_j = Jam density (vehicles/km)

The capacity for straight and curved sections was calculated separately to assess the impact of horizontal alignment on roadway performance. Capacity loss at curved sections was determined by comparing capacity at straight and curved sections

5. Result and Discussion

5.1 Traffic distribution

The geometric and structural design of pavements is largely influenced by the composition of vehicles within the traffic stream. Analyzing traffic composition provides insights into the distribution of various vehicle types. The study indicates that motorcycles constitute the largest share of the traffic flow, while trucks represent the smallest. The proportion of cars exhibits minor fluctuations with varying traffic volumes. A detailed breakdown of vehicle distributions across different sections is provided in Table 2.

Table 2 Traffic distribution at different sections

S. N	Location Name	Traffic Distribution of different category vehicle									
		Two-Wheeler		Truck		LCV		Bus		Car	
		Vehicle	%	Vehicle	%	Vehicle	%	Vehicle	%	Vehicle	%
1	Chovar	1897	70.13	47	1.74	267	9.87	75	2.77	419	15.49
2	Manadev mandir Dakshinkali	1072	75.02	29	2.03	47	3.29	43	3.01	238	16.66
3	Taudaha site 1	1997	74.32	44	1.65	199	7.48	57	2.14	383	14.4
4	Taudaha site 2	2098	68.88	67	3.12	327	10.74	95	2.2	459	15.07
5	Bhanjyang Dakshinkali	2135	69.86	74	2.42	303	9.91	76	2.49	468	15.31

5.2 Speed distribution

The PCU factor is determined by comparing the average speed of passenger cars to the average speed of other vehicle types. This is achieved by dividing the mean speed of passenger cars by the mean speed of each other vehicle type. Videos were recorded and displayed on a large screen to facilitate data extraction. The time each vehicle type took to cover the trap length was timed with a stopwatch accurate to 0.01 seconds. It was observed that vehicle speeds decreased significantly at curve sections, with the average speeds for different sections listed in Table 3.

Table 3 Distribution of speed of different category vehicle at different section

S. N	Location	Speed of vehicle (Km/hr)					
		Road section	Two-Wheeler	Car	LCV	Truck	Bus
1	Chovar	Straight	60.64	55.74	52.7	51.19	51.82
		Curve(R=90m)	41.05	38.24	37.73	36.69	36.48
2	Mahadev mandir Dakshinkali	Straight	59.06	56.4	53.97	52.83	52.69
		Curve(R=68m)	41.75	37.63	37.23	36.41	35.98
3	Taudaha site 1	Straight	57.51	51.45	49.33	46.58	48.46
		Curve(R=32m)	36.45	31.56	31.47	30.58	30.65
4	Taudaha site 2	Straight	56.64	51.74	48.7	47.19	47.82
		Curve(R=104m)	40.55	37.74	37.23	35.99	35.78
5	Bhanjyang Dakshinkali	Straight	55.39	51.39	48	46.09	46.82
		Curve(R=151m)	41.05	38.24	37.72	36.29	36.22

Speed observations were carried out for vehicles traveling under free-flowing conditions. The Table 3, shows that two wheelers have higher speed and it was also observed that the speed of each category vehicle decreases at the curve section. In the Bhanjyang-Dakshinkali road section, the observed speed was lower despite the larger curve radius. This can be attributed to the influence of road surface condition that were not considered in this study.

5.3 PCU value for vehicles

Table 4 shows the PCU values for the different category vehicle that were determined at various highway sections. This table demonstrates how PCU values vary by vehicle type in relation to the curve radius. The PCU factor is derived from the mean speed values and the projected area of each vehicle class. For this study, cars, jeeps, and vans (e.g., Altroz ,Maruti Suzuki 800 DX,) are assumed to have a projected ground area of 5.39 square meters (Nepal Automobile Survey, 2016) as standard passenger cars. The PCU values for each vehicle type were calculated using Chandra's equation

Table 4 PCU values of different categories of vehicles at different sections

S. N	Location Name	Section	Passenger Car Unit (PCU)				
			Bus	Truck	LCV	Two-Wheeler	Car
1	Bhanjyang Dakshinkali	Straight	5.6489	3.6452	2.5445	0.2066	1
		Curve(R=151m)	5.4333	3.4450	2.4096	0.2074	1
2	Taudaha site 2	Straight	5.5685	3.5844	2.5250	0.2034	1
		Curve(R=104m)	5.4282	3.4283	2.4094	0.2072	1
3	Chovar	Straight	5.5359	3.5598	2.5137	0.2046	1
		Curve(R=90m)	5.3946	3.4074	2.4089	0.2074	1

4	Mahadev mandir Dakshinkali	Straight	5.5079	3.4896	2.4835	0.2126	1
		Curve(R=68m)	5.3838	3.3788	2.4027	0.2007	1
5	Taudaha site 1	Straight	5.4639	3.6112	2.4790	0.1992	1
		Curve(R=32m)	5.2986	3.3743	2.3759	0.1928	1

Table 4 displays the calculated PCU values for both straight and curved road sections, revealing that buses have the highest PCU values, followed by trucks, LCVs, cars, and two-wheelers. Although trucks exhibit a higher speed-area ratio compared to buses, their PCU is lower. The PCU values derived from this study differ from those outlined in the NRS 2013 standards. This is because the PCU values are same for Bus, Truck, Minibus, Tractor with trailer in NRS 2013 but due to the different projected area of vehicle in ground is different it was observed different PCU values. The projected area on the ground for bus was 27.74 square meters and truck was 17.62 square meters which reflect the PCU values for bus was higher than the truck. Shalkamy et al. (2015) examined the effect of horizontal curvature on PCU values for different vehicle categories and found that buses exhibited higher PCU values than mini trucks across all curve radii. According to Malla et al. (2023), the PCU values for a two-lane, two-way undivided highway are 5.5414 for buses, 4.006 for trucks, 2.7693 for LCVs, and 0.2228 for two-wheelers on an upgrade of +2.1%, and 5.3426, 3.6272, 2.5495, and 0.2138 respectively on a downgrade of -2.1%. Similarly, according to Khadka (2017), the PCU values obtained using the Modified Homogenization Coefficient method were 0.23 for two-wheelers and 3.01 for trucks. Banskot (2018) reported a PCU value of 3.32 for trucks. These values closely match those obtained in Table 4, thereby validating the results.

5.4 Relationship between PCU and radius of curve

Data from the first five sections was used to establish the relationship between PCU and the radius of curve, and additional radii were used for validation. The results of the investigation showed a linear relationship between the curve radius and PCU values for various vehicle category. After evaluating a number of equations, it was determined that linear equations best captured the relationship between curve radius and PCU.

Table 5 provides a comprehensive summary of the relationship between the PCU of different vehicle types and the radius of the road curve, along with their respective R^2 values.

Table 5 Relationship of PCU of different category vehicles with radius of curve

Vehicle type	Relation between passenger car unit and radius of curve of road R	R^2 value
Bus	PCU = 0.0011R + 5.2896	0.8112
Truck	PCU = 0.0007R + 3.3482	0.9021
LCV	PCU = 0.0002R + 2.3843	0.8935
Two-wheeler	PCU = 0.00010R + 0.1921	0.7188

The relationship between PCU and Radius of curve shows that PCU values increases linearly with increase in the radius of curve. It was clearly observed in case of higher category vehicle while there is no significant changes in PCU values for light category vehicles, the PCU values for light category vehicles remain constant as the radius of curves increases this is due to that the speed of higher categories vehicles drastically changes in the curve section i.e. different in sharp and smooth curve but for the light category vehicle speed does not changes too much while travelling from straight to curve section. From observed data there is slightly increase in PCU for light category vehicle, but the significant effect of radius was not observed in data range. According to Shalkamy(2015), the PCU for light vehicles was only affected by carriageway width rather than the radius of curve.

5.5 Validation of developed relationship between PCU and radius of curve

To validate a mathematical model, it must be tested with appropriate methods. This study developed models using data from five sections with different radii (32m, 68m, 90m, 104m, and 151m) and validated them with an additional section having a 221m radius. To validate the models, the study used a two-tailed t-test due to the use of independent data sets for both model development and validation (Aman and Parti, 2021). The PCU value for different vehicle categories were collected at the 221m radius section, with road element measurements detailed in Table 6. PCU values were estimated using the proposed models, and statistical comparisons of observed and model values were made to assess significance. The t-test assessed the differences between group means against the combined standard error, with a significance level of 5%.

Table 6 Detail of road section for validation

S.N.	Radius of Curve (m)	Trap length (m)	Carriageway width(m)	Shoulder width
1	221	40	6.5	0.3 m

For validation the proposed PCU model for the radius of the curve of the road, the following hypotheses were tested:

Null Hypothesis (H_0): The difference between the actual and predicted PCU values is zero (H_0: $\mu_1 = \mu_2$).

Alternative Hypothesis (H_a): The difference between the actual and predicted PCU values is not zero (H_a: $\mu_1 \neq \mu_2$).

Level of significance(α) = 0.05 Confidence interval (C.I) = 0.95

$$t_{value} = \frac{(x-\mu)\sqrt{N}}{S} \tag{8}$$

Where, $\bar{X}$ = Sample mean,
N= number of observations and S= sample standard deviation

The critical value of t at level of significance (α) = 0.05 and degree of freedom = 5 for two tailed tests are listed in Table 7

Table 7 Comparison of Actual vs. Predicted Values Using a t-Test

S. N	Vehicle type	Mean value				P -value	comment
		model	Observed	t0.05	tcritical		
1	Truck	3.5	3.49	-0.728	2.57058	0.48	H0 is true
2	Bus	5.53	5.52	-0.413	2.57058	0.678	H0 is true

t-statistic is less than the t-critical value and the p-value is more than the significance level ($p > 0.05$), we fail to reject the null hypothesis. This suggests that there is no significant difference between the actual and predicted PCU values, validating the proposed PCU estimation models against the field data.

5.6 Flow characteristics and capacity estimation

Based on the outlined methodology, the speed-density relationship is linear under uninterrupted and heterogeneous traffic condition (Gautam & Jain, 2018). The study analyzed the relationship between flow and speed by graphing field data and utilizing Greenshield's linear speed-density assumption. PCU values and speeds used to calculate mean stream speed and flow. The capacity was determined from the speed flow diagram at maximum flow or from the flow density relationship at optimal density. The flow characteristics, derived from the observed data points across different road sections, are shown in Table 8

Table 8 Summary of flow characteristics

S. N	Location Name	Road section	Free flow speed (kmph)	Optimum density (PCU/km)	Jam density (PCU/km)	Maximum velocity (Kmph)	Maximum flow (PCU/hr)
1	Chovar	Straight	64.519	44.98	89.96	32.26	1451
		Curve(R=90m)	47.066	49.41	98.82	23.53	1163
2	Mahadev mandir Dakshinkali	Straight	64.058	40.89	81.79	32.03	1310
		Curve(R=68m)	49.588	39.5	78.99	24.79	979
3	Taudaha site 1	Straight	65.389	41.334	82.69	32.7	1352
		Curve(R=32m)	43.218	47.29	94.59	21.61	1022
4	Taudaha site 2	Straight	61.02	43.63	87.26	30.51	1331
		Curve(R=104m)	45.918	48.52	97.04	22.95	1114
5	Bhanjyang Dakshinkali	Straight	59.545	42.38	84.77	29.77	1262
		Curve(R=151m)	46.305	50.2	100.4	23.15	1162

The table 8 clearly shows that straight section exhibits higher free flow speeds due to the absence of geometric constrains. The maximum free flow speed for the straight section was found 65.389 kmph for taudaha site 1 and for the curve section free flow speed relatively reduced. Optimum and jam density for straight section was found to be lower than the curve section which shows that less vehicle congestion and smooth traffic flow at straight section. Maximum speed corresponding to maximum flow was also found higher at straight section. The relationship follows the Greenshields model that speed and density linearly as vehicles move freely in less congestion. From the graphical representation it has been found that maximum flow occurs at optimum density with maximum velocity.

5.7 Summary of roadway capacity

The flow characteristics, derived from the observed data points across different road sections, are summarized in Table 9.

Table 9 Capacity at straight and curve section of different road section

S. N	Location	Capacity at straight section (PCU/hr) per lane	Capacity at Curve section (PCU/hr) per lane	Capacity Loss %	Radius of Curve(m)
1	Bhanjyang Dakshinkali	1262	1162	7.92	151
2	Taudaha site 2	1331	1114	16.30	104
3	Chovar site 1	1451	1163	19.85	90
4	Mahadevmandir Dakshinkali	1310	979	24.41	68
5	Taudaha site 1	1352	1022	25.27	32

The study found that capacity at curve section was relatively low as the driver reduced the vehicle speed to navigate the curve safely which results in capacity reduction. The capacity loss at the curve section having radius 151 m was found 7.92% and decreasing the radius of curve to 104 m, 90 m, 68 m,32 m, the capacity loss increased to 16.30%, 19.85%,24.41%, 25.27% respectively.

6. Conclusion

The study reveals that two-wheelers dominate traffic composition across all locations. The study carried out dynamic PCU method for PCU estimation and found that radius of curve has also effect on PCU values for heavy vehicle category. The PCU values increases with increase in the radius of curve, however there is no significant changes in PCU values for light category vehicle. The PCU values of Bus and Truck ranges from 5.2986 to 5.4333 and 3.3743 to 3.4450 on varying radius of curve from 32m to 151m respectively. The research determine the capacity of two-lane undivided roads for different curve radii, based on flow rates observed at 15-minute intervals. It was found that capacity loss is 25.27% at the curve section having radius 32 m and 7.92% at the curve section having radius 151m. The study concluded that capacity loss of two-lane undivided roads decreases with increase in radius of curve section. When designing new roadway facilities to accommodate future traffic demand, it is essential to consider the radius of the curve as a key design factor, as it significantly influences roadway capacity and overall traffic performance. Proper curve radius selection can help minimize capacity loss and improve traffic flow under heterogeneous conditions. Additionally, further research is recommended to classify buses and trucks into at least two to three sub-categories based on their dimensions, as variations in size and weight impact vehicle speed, maneuverability, and roadway capacity differently. Future studies could also focus on intersections and divided carriageways to enhance understanding of PCU estimation and capacity variations under diverse traffic conditions. While this study employed Greenshield's model for speed-density analysis, future research could explore alternative traffic flow models to determine their suitability for mixed traffic environments.

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