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Effects of Roadside Friction on Traffic Flow Parameters and Level of Service of Urban Arterials. A Case Study of Pokhara Metropolitan City

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Abstract
This paper attempts to quantify the impact of roadside friction on traffic flow parameters and LOS of urban arterials in Pokhara. The roadside friction factor considered for this research are pedestrains crossing the road, pedestrains walking along the road, motorcycle parkings, vehicle parkings and stopping and slow moving vehicles. Based on data congregated from study sections, speed, flow and density models were developed considering the various side friction elements. The road sections with high impact of roadside friction are found to operate at LOS C which indicated more marked restriction to passing and overtaking and the road sections with comparatively low impact of roadside friction are found to operate at LOS B. A sensitivity analysis was performed to evaluate impact elasticity of these RSF's on the LOS and it was moderate to high. This finding emphasizes the necessity of including side friction effects in all traffic studies for efficient urban road planning.

Keywords
Arterials, Level of Service(LOS), Roadside Frictions(RSF's), Traffic Flow Parameters

1. Introduction

1.1 Background

Recent years have seen a large increase in road traffic and transportation demand in many cities, which has led to poor traffic system performance.Pokhara's road infrastructure has undergone great progress, however unwelcome side friction elements are reducing the effectiveness of the roadway, particularly in metropolitan areas. The amount of interaction between regular traffic flow parameters and other neighboring activities, including on-street parking, pedestrian activity, and non-motorized vehicles, is referred to as roadside friction. These activities hinder through traffic and has significant effect on the proper functioning of the road as a whole. On-street parking affects the capacity of the road in two basic ways. It starts by enclosing the traffic flow, which reduces the width of the route. As a result of having to fit inside this smaller area, vehicles move more slowly overall. Second, frequent parking and unparking operations create complex situations that clog city roadways with traffic[1]. There have been very few research that attempt to quantify the effects of side frictions, despite the fact that it is well recognized that roadside activities lead to a decrease in the speed of the usual traffic stream and, as a result, an increase in travel time. The Highway Capacity Manual (2010) discusses how road side frictions affect urban roadways, and highway categorization schemes naturally take these effects into account[2].

The issue of side friction on urban roadways in major cities is present in Nepal, a growing nation. These roadside frictions, along with the various traffic conditions present in developing countries, have a detrimental effect on urban level of service, travel speed, vehicle flow rate, and vehicle density, and they pose a significant risk to the safety of road users. The absence of such research in the context of Nepal during urban road development is the rationale for the choice of this issue.

1.2 Objective of the study

The specific objective of this research are as followings:
• to prepare relationship model for speed, flow-rate and density considering the roadside friction factors on urban arterials.

• to analyze the impact of roadside friction on level of service.

2. Related Works

Salini et al.[3] came to the conclusion that roadside friction on a roadway influences the maximum vehicle flow rate and Level of Service(LOS) in addition to limiting continuous or smooth vehicular flow movement.

[4]In target locations, various friction components differ throughout a segment of the road. In order to accurately capture variable friction data during target hours that account for peak hours and representative length of 100m, continuous video records from an elevated point were used. These records included pedestrians, parked cars, off and in parking vehicle movement, street vendors, pedestrian streets, and any other friction data.

[5] Volume or flow rate, speed, and density are regarded as the three macroscopic factors that define traffic streams. Daily volume is commonly used in planning for normal trend study and for traffic flow volume prediction. Volume is simply the number of vehicles that pass a specific place on a roadway, a given lane, or direction of a highway in a specified period.

Roadside friction is a typical occurrence in developing nations. According to their research, one of the roadside friction events in India that had the biggest impact on the average speed of all the sections they investigated at was pedestrian activity[6].

For determining the operational effectiveness and level of service of transportation facilities, such as highway portions, speed, flow, and density are essential. Under conditions of uninterrupted flow, speed is defined as the product of the flow rate and the density. Conventional designs, operating procedures, and LOS analysis are predicated on a 15-minute peak traffic period during the peak hour.To connect the peak flow rate to hourly quantities, the peak-hour factor(PHF) is determined. For determining the operational effectiveness and level of service of transportation facilities, such as highway portions, speed, flow, and density are essential[2].

In order to validate the models developed[7],multiple linear regression was used. Further, the strength of the relationship between dependent and independent variables is measured by correlation. The goodness of fit is measured by linear regression using the R2-value and R2-Adjusted. Any association with an R2-value of more than 0.80 will be deemed to be the best fit.Each parameter was measured at an hourly rate and then used to do the regression analysis.Then, to test for linear fitness, plot the predicted values as the ordinate and the observed values as the abscissa. If there was no difference in the values, then all the points, both observed and anticipated, should sit on this line.

Based on free flow speed and average travel time, urban street LOS are calculated. Urban streets are classified according to their quality of service using the free flow speed, and the average journey time (LOS). Direct field observation or consideration of the road's functional and design categories can both be used to determine the free flow speed. The surveyors must identify the urban street class, its FFS, and the segment length in order to calculate the running time for a segment[2].

[8] A sensitivity analysis was done to determine impact elasticity. For instance, the impact elasticity term of pedestrian mobility for density result is -0.29 if a 10 percent fall in density is caused by a 2.9 percent increase in pedestrian crossings. The value would be 0.29 in the case of a 10 percent rise. The greater the elasticity, the greater the influence of the input on the result.

3. Methodology

The first step entails gathering traffic data from the study sections. From the traffic data, the various friction elements that contribute to roadside friction were identified, and spot speed data were also taken.Then after data analysis; speed, flow rate, density models were developed considering the RSF elements as described in the subsections. Additionally, the study sections were categorized as per their level of services considering the various road side friction factors.

3.1 Site Selection

First, a variety of traffic flow conditions, including flow intensity, traffic mix, the proportion of heavy vehicles, and side friction levels, were taken into consideration when choosing roadways. Second, the location and the physical and geometric condition of the roadways were taken into consideration. The selection of study locations and segments was based on more specific criteria, which were stated as;

straight alignment, located in a plain terrain, easy to observe roadside frictions. While the selection of roadways was generally based on physical, environmental, and traffic characteristics.

On the basis of above criterias, three different un-divided two-way urban roads were selected: Ranipauwa Chowk to Hospital Chowk, Nadipur Chowk to Bagar Chowk and Hallanchowk to Barahi Chowk as shown in Figure 1.

Figure 1: Pokhara city map showing study road section of urban arterials

3.2 Sampling Technique

The sample were collected on any working day other than the day that a special event is most likely to take place such as a game, an exhibition, etc.Based on the sample design, the appropriate number for statistical analysis was gathered. Because it is difficult to directly manually count using a stopwatch in these section, continuous video records were made utilizing video cameras.In the locations of the higher friction road segment (I, III, V), one set of data was gathered .Data from another set was gathered away from the locations with minimum friction in the road sections (II, IV, and VI).The targeted time was from 2:00 pm to 6:00 pm. The representation length of 100m was taken for each road sections.

3.3 Traffic Data

Data on traffic was gathered via videography. Data were gathered from the road segments during during daytime covering the peak hour. The portion of a straight road was chosen for video data collection. The video camera was placed on a tripod stand and kept on the terrace of a building close to the edge of the roads in order to capture the passage of vehicles for wide range. The camera had been set up so that it could easily capture the entire road portion.The number of traffic vehicles was counted for each 15-minute period, and the flow rate (veh/hr) was derived later.

3.4 Speed Data

Spot speed was chosen in an area where the drivers were not aware that a study was being done in order to prevent biases.Using ”speed radar gun/speeders,” two sets of spot speed data were gathered in order to better understand the variations in travel speed both inside and outside the bottleneck sections of the study sections.Every five minutes, three spot speed measurements were taken. Three different types of vehicle were considered for heterogeneity. Sample size of 144 (3*12*4) per day for each sections of road was taken.

3.5 Friction Data

Five dynamic roadside friction factors, including pedestrian crossing road movements, pedestrian walking or standing near the road, bicycles, vehicles, and motorcycles’ parking maneuver, stopping, and slow-moving vehicles, have been identified as the major factors affecting traffic performance and level of services after visiting some road stretches as part of a preliminary survey for reconnaissance.The number of roadside friction elements were also counted for each 15-minute period parallel with other traffic datas and speed datas.

4. Data Analysis and Interpretation

The chapter deals with the presentation and analysis of the data collected from the different areas of the city. The collected data includes spot speeds, traffic flow count (bicycles, motorcycles, cars, jeeps, pickups, buses, trucks, tractors, and roadside friction factors like pedestrian crossing the road, pedestrian walking side by the road, bike parkings, vehicle parkings, stopping vehicles, within one meter of the road.

Heterogeneous traffic stream was considered on the two-way carriageway but the traffic flow was not suitable for the free flow traffic due to the presence of roadside factors.In order to evaluate traffic performance, five LOS were proposed in both HCM 2000 and HCM 2010, and the same methodology for calculating and analyzing LOS was used in this research.

The Excel’s statistical method i.e correlation and multiple regression analysis of hourly traffic data and hourly speed data were used to build the speed-density and speed-flow model while accounting for dynamic friction variables on Pokhara urban arterials. The Impact of the RSF variables on the LOS of the roads sections were analyzed using Impact elasticity.

4.1 Spot Speed Data

The 85th percentile speed was used for traffic stream effectiveness and performance. Hence, the traffic speed within the high roadside friction area was low as compared to outside area with low roadside friction.

Also the operational speed was restricted near and within the high friction area (Section I, III, V) with the value of 22 km/hr, 24 km/hr, 25 km/hr and standard deviation of 5, 7, 7 respectively. But the operational speed outside the high friction area (Section II, IV, VI) was 48 km/hr, 51 km/hr, 45 km/hr and standard deviation was 8, 10, 9.

The speed started to reduced during the evening time because of higher traffic volume and roadside factors. The basic statistical speed data for 15 minutes interval is showed in Table 1.

Table 1: Basic statistical spot speed data in km/hr

Road Name	Ranipauwa Road		Bagar Road		Lakeside Road	
Section	I	II	III	IV	V	VI
Number of data	288	288	288	288	288	288
Mean	17	39	18	39	18	37
Standard Deviation	5	8	7	10	7	9
Minimum	4	19	5	7	4	12
Maximum	24	53	42	63	31	55
Range	20	34	37	56	27	43
85th Percentile	22	48	24	51	25	45

4.2 Traffic Stream and Roadside Friction Data

The traffic stream was heterogenous in nature consisting of bicycles, motorcycles, cars, jeeps, pick-ups, buses, tractors, trucks. There was no provision of separate vehicle flow lanes. As motorcycles are motorized to change speed, they are not considered as RSF factors.

At the time of data collection, the major contributor to roadside friction was found to be pedestrian crossing and walking around the road in an unorganized manner. Such activity resulted affecting the smooth flow of the traffic stream and forced to slow down and stop frequently. Other RSF elements included bike parking and maneuvering, vehicles parking and maneuvering, slow moving and stopping vehicles. Hence prior consideration was given to dynamic factors.

Among all the surveyed section, the ranipauwa road-section II was found to have lowest RSF i.e 7.32 % of the total road users which also have the lowest pedestrian crossing and walking along the road section of 100 m as compared to all the road section surveyed. Therefore, it has highest percent of traffic stream i.e 92.68 % of the total road users.

Similarly, the lakeside road-section V was found to have highest RSF i.e 51.97 % of the total road users which also have the highest pedestrian crossing and walking along the road section of 100 m as compared to all the road section surveyed. Therefore, it has lowest percent of traffic stream i.e 48.03 % of the total road users. The result also show that the roadside friction class is medium for Ranipauwa road- Section II because RSF's houely rate is between (300-499 RSF's per hour).

And all other road section i.e Bagar Road- Section III and IV, Lakeside Road- Section V and VI and Ranipauwa Road- Section I lies in very high friction class with RSF's hourly rate (greater than 900 RSF's per hour).Table 2 show the total number of road users in different road and its surveyed section.

The total road users count of four hours (2:00 pm to 6:00 pm) for two days in July 2022 is shown in Table 2 and the classification of dynamic roadside friction is how in Table 3.

4.3 Traffic Composition

The traffic was categorized into four parts namely; bicycles, motorcycle, private vehicles (cars, jeeps, pick-ups), buses and goods vehicles (micro buses, tractors, medium and heavy trucks). The composition of traffic stream as shown in the Figure 2, Figure 3 and Figure 4 indicated that bicycles ranged from 1.17 % to 7.72 %. Motorcycles ranged from 67.55 % to 73.81 % . Private vehicles ranged from 18.84 % to 26.68 % and public vehicles ranged from 0.91 % to 6.17 %.

Table 2: Total Road users count of four hours for two days in July 2022

Road Name	Ranipauwa Road		Bagar Road		Lakeside Road	
Traffic & RSF Factors	Section I	Section II	Section III	Section IV	Section V	Section VI
Bicycles	470	242	159	108	859	799
Motorcycle	8857	7903	9289	7535	8476	7052
Vehicle (4 wheeler or above)	3773	3566	3106	2596	2444	1825
Pedestrain Crossing Road /100 m	690	178	2508	361	902	193
Pedestrain Along Road /100 m	5201	661	5725	1567	10137	6388
Bike Parking Maneuvers/100 m	708	23	1149	619	1115	364
Vehicle Parking Maneuvers/100m	357	32	505	283	313	109
Stopping Vehicles	210	31	416	122	279	133

Table 3: Classification of dyanamic roadside friction

RSF Class	Percentage	RSF's / hr (Hidayanti et.al,2012)	Road Section	RSF's Percentage	Traffic stream Percenatge
Very Low	<3	<100			
Low	3-5	100-299			
Medium	6-10	300-499	Ranipauwa Road (Section II)	7.32	92.68
High	10-19	500-900			
Very High	>20	>900	Bagar Road (Section IV)	22.37	77.63
			Ranipauwa Road (Section I)	35.35	64.65
			Bagar Road (Section III)	45.07	54.93
			Lakeside Road (Section VI)	42.61	57.39
			Lakeside Road (Section V)	51.97	48.03

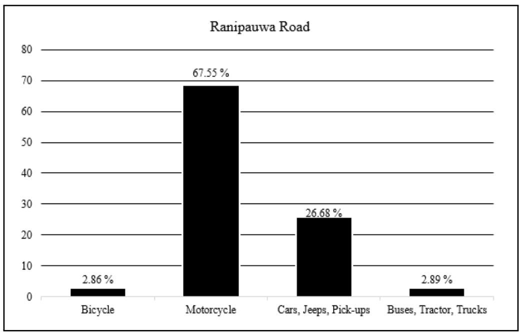

Figure 2: Traffic Composition of Surveyed Sections on Ranipauwa Road

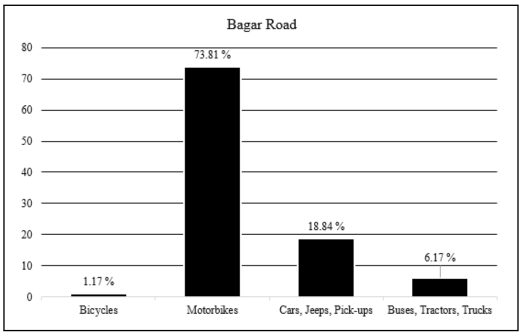

Figure 3: Traffic Composition of Surveyed Sections on Bagar Road

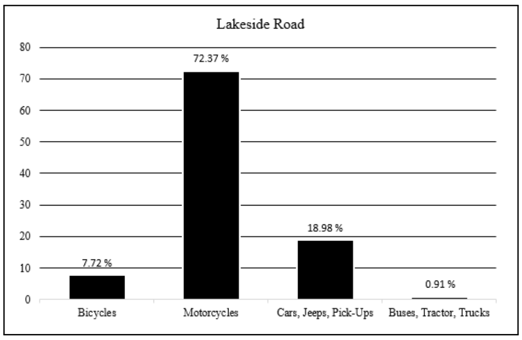

Figure 4: Traffic Composition of Surveyed Sections on Lakeside Road

4.4 Simple Relationship Between Speed, Flow-rate and Density

Figure 5, Figure 6 and Figure 7 shows there is high correlation between speed and density and between flow and density while the correlation between speed and flow rate is not strong. A simple linear equation between speed and density and a quadratic eqaution between flow rate and density has been established.

$$Rate = 4*(Peak15min)$$

$$Density = (Rate/AverageHourlySpeed)$$

$$Speed(km/hr) = 49.066 - 0.5743\rho$$

$$FlowRate(veh/hr) = 470.62 + 16\rho - 0.148\rho^2$$

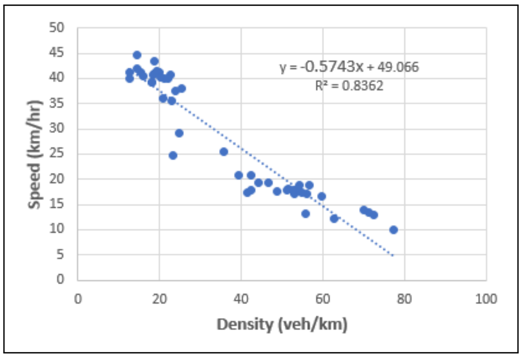

Figure 5: Relationship between Speed and Density of surveyed urban arterials

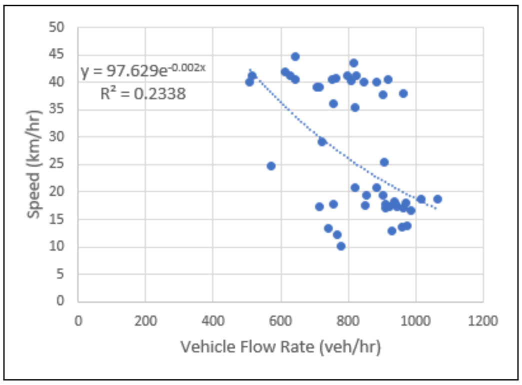

Figure 6: Relationship between Speed and Flow-rate of surveyed urban arterials

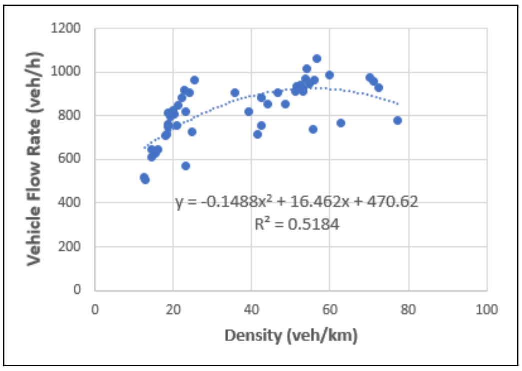

Figure 7: Relationship between Flow-rate and Density of surveyed urban arterials

4.5 Multiple Linear Regression Analysis

Using HCM 2000, the flow rate and corresponding vehicle density as the ratio of vehicle flow rate to their mean speed was calculated. And the results from MLRA are showned in Table 4, Table 5 and Table 6.

Here,

S = Speed (km/hr)

ρ = Density (veh/km)

PCU = Passenger Car Unit (PCU/hr)

V_V = Vehicle flow

V_B = Bicycle Flow

V_M = Motorcycle Flow

V_{PEDC} = Pedestrain crossing per 100 m

V_{PEDWS} = Pedestrain walking side of road per 100 m

V_{MPM} = Motorcycle parking and maneuvering per 100 m

V_{VPM} = Vehicle parking and maneuvering per 100 m

V_{SV} = Stopping and slow moving vehicles per 100 m

The mathematical equations developed are as follows:

Model 1:

$$Density(Veh/km) = 65.079 - 1.529S + 0.021V_M + 0.034V_V + 0.021V_{PEDC}$$

Model 2:

$$Flowrate(Veh/hr) = 3.67\rho - 4.78S + 1.03V_{MPM} + 0.12V_{PEDWS} + 0.17V_{PEDC} + 0.47V_V + 0.32V_M$$

Model 3:

$$Speed(km/hr) = 52.392 - 0.0476\rho - 0.028PCU - 0.025V_{PEDC}$$

4.6 Models Validation

The plots of the observed value vs the predicted value was generated, in order to assess the correctness of the developed models for speed, density, and flow rate.

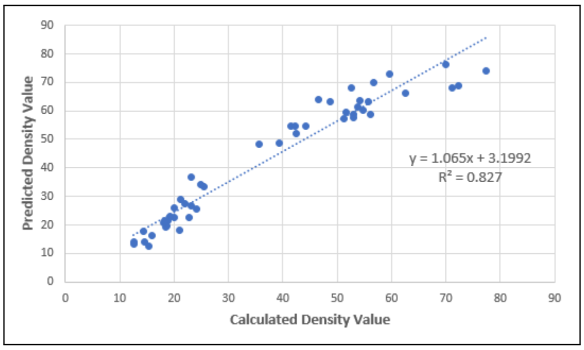

Figure 8: Plot between Calculated density vs Predicted density

Table 4: Results obtained from MLRA for Density Model

	Coefficients	t Stat	P-value	Multiple R	R Square	Adjusted R^2
Intercept	65.079519	4.69713	3.58E-05	0.852	0.826	0.812
V_M	0.0210437	-2.6676	0.01127			
V_V	0.0343168	-2.3307	0.02533			
V_{PEDC}	0.0218051	2.08245	0.04427			
S	-1.529848	-9.9923	4.69E-12			

Table 5: Results obtained from MLRA for Flow-rate Model

	Coefficients	t Stat	P-value	Multiple R	R Square	Adjusted R^2
V_M	0.3214979	9.49995	1.82E-11	0.841	0.823	0.794
V_V	0.4770811	5.68358	1.68E-06			
V_{PEDC}	0.1693828	-2.2383	0.03131			
V_{PEDWS}	0.1259503	-3.1334	0.00337			
V_{MPM}	1.0337398	4.527	6.02E-05			
S	-4.7833639	2.39657	0.02172			
ρ	3.6797624	3.55949	0.00104			

Table 6: Results obtained from MLRA for Speed Model

	Coefficients	t Stat	P-value	Multiple R	R Square	Adjusted R^2
Intercept	52.392353	11.3411	1.33E-13	0.857	0.834	0.822
ρ	-0.0476925	-9.9923	4.69E-12			
PCU	-0.028091	2.39657	0.02172			
V_{PEDC}	-0.025618	-3.3137	0.00207			

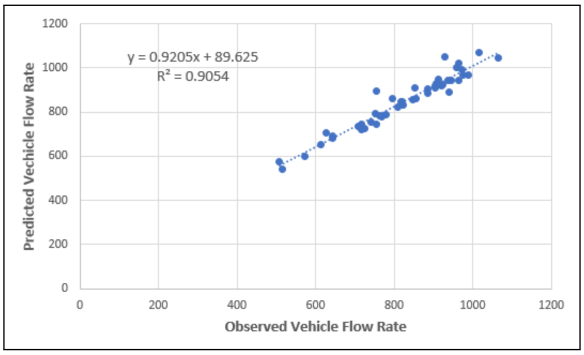

Figure 9: Plot between Observed flow-rate vs Predicted flow-rate

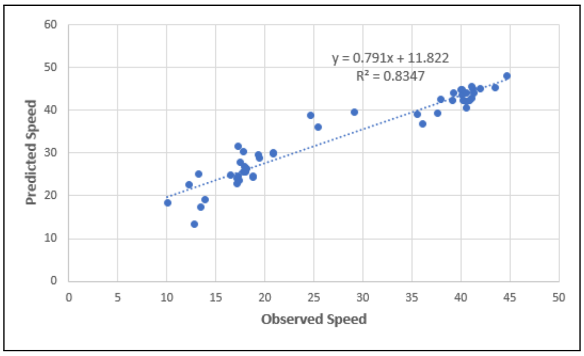

Figure 10: Plot between Observed speed vs Predicted speed

It was noted that there was not much scattering in these instances i.e points lies on the same line.

4.7 Imapct of Roadside Friction on Level of Service of Roads

LOS of the different road section was evaluated using HCM 2000 by determining the FFS of the road sections using functional and design criterias, average travel speed and average time delay. All the roads section resemble to Class IV. Further the LOS of road section (I,III,V) belongs to C which has higher roadside friction elements.To the contrary,LOS of road sections (II,IV,VI) belongs to B which has Lower roadside friction elements.For example:

$$RSFI_{LOS} = [((35.35-7.32)/35.35)*100]/[(58.01-20.80)/58.10)*100] = 1.35$$

5. Conclusion and Recommendations

Firstly, the fundamental relationships between the traffic flow parameters (speed, flow-rate and density) were found significant based on the R^2-value. Then, mathematical equations were developed from multiple linear regression analysis, taking into consideration

Table 7: Analysis of RSF imapcts on Level of Service

Section	LOS	RSF Count	ρ	Impact Elas-ticity	Impact
I II	C B	35.35 7.32	58.1 20.8	1.35	High
III IV	C B	45.07 22.37	57.6 22.1	0.81	High
V VI	C B	51.97 42.61	50.7 17.1	0.27	Mode-rate

roadside friction caused by events like pedestrian crossings, people wandering alongside the road, motorcycle and vehicular parking, and slow-moving traffic. Comparing the observed and predicted values has revealed that future observed RSF values can be successfully accounted for in predicting traffic flow parameter values. Similarly, pedestrian crossing the road, unstructured walking along the road and on-road motorcycle parking were discovered to be the main causes of roadside friction effecting the traffic flow parameters. The surveyed roads segments were operating at LOS B for the segment with lower RSF's and at LOS C for segments with higher RSF's. The impact of RSF's on the LOS of the roads was then evaluated using sensitivity analysis to evaluate impact elasticity which were found to be moderate to high.

Therefore, it is necessary to develop off-street parking along the roads. Pedestrians should be provided with accurate information and instruction to use the footpath. The scope of this study could be expanded to include a wider variety of road segments and market segments for Nepali roads.

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