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Determination of Motorcycle Equivalent Unit and Road Capacity: A Case Study of Selected Road Sections of Kathmandu Valley

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Abstract

The research focused on road congestion in Kathmandu Valley, Nepal, caused by the prevalence of small motorized vehicles, especially motorcycles. The objective of the study was to quantify the impact of different vehicle classes on congestion by calculating Motorcycle Equivalent Units (MEU) and determining roadway capacity using speed and effective space parameters. The field data collected over two locations in Kathmandu Valley were analyzed using Speed Estimation from Video Data (SEV) software that revealed a strong correlation between vehicle speed and effective space, represented by a quadratic non-linear model. MEU values were determined for different vehicle classes, and fundamental speed-flow-density relationships were used to calculate roadway capacity. Vehicles like motorcycles, standard cars, big cars, utility, minibusses, buses, light commercial vehicles, two/three-axle trucks, and multi-axle trucks had MEU values of 1, 3.32, 4.91, 4.65, 9.22, 12.22, 6.72, 13.57 and 18.04 respectively. The study indicated peak capacities during the evening hours on specific road sections. For instance, the Gatthaghar-Kaushaltar and Balkumari-Gwarko sections reached their maximum capacities at 12,335 and 20,589 (motorcycles per hour per direction), respectively. The study emphasized the significant influence of speed on effective space and roadway capacity, suggesting further exploration of additional factors like driver characteristics, gender, age, income, road geometry, and level of service using MEU, along with the potential for developing a motorcycle simulation model in Kathmandu valley.

Keywords: Speed, Effective space, Motorcycle equivalent units Roadway capacity

1.Introduction

The traffic flow in developed countries is dominated by homogenous traffic with lane discipline. Road congestion is mainly caused by increased numbers of imported cars, improper rider conduct, and a lack of funding for infrastructure (Thomson & Bull, 2002). Countries like Taiwan (82%), Malaysia (64.20%), and Vietnam (95%) struggle with the dominance of tiny motorized vehicles like motorcycles and scooters. Motorcycles are a popular means of transportation due to their mobility, affordability, and low parking space requirements. It is impossible to ignore the fact that motorcycle riders are the majority of road users in these countries, and therefore their consequences should be taken into account (Hsu, et al., 2003). In Nepal, motorcycles accounted for 78.780% of the total vehicle population, with a 19.01% increase in ownership compared to the previous year for the fiscal year 2019/020 (DoTM, 2021). Due to population growth, increasing vehicle numbers, and inadequate road infrastructure, urban regions in Nepal, such as Kathmandu Valley, are experiencing traffic congestion. The vehicle-road ratio per km in the valley has increased 83 times in five years, with evening traffic congestion (4 p.m. to 5 p.m.) on six significant routes in Kathmandu (Bista & Paneru, 2021). The number of motorcycles registered in the Bagmati zone alone has dramatically increased by about 207.28% in the last decade (DoTM, 2019). It is seen that motorcycle traffic has a significant influence on road traffic congestion inside the valley.

In mixed traffic flow, motorcycles often occupy the entire lane, both ahead and to the sides of a running vehicle. However, many motorcycles do not strictly adhere to lane rules. The static and dynamic characteristics of mixed vehicles occupying the same lane, as well as discipline and maneuver activities,

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significantly impact roadway capacity. The presence of different types of vehicles with varying sizes and speeds can affect traffic operations in multiple ways. Motorized two-wheelers, which are highly mobile, penetrate the limited spaces available between two large vehicles, covering the entire lane, eventually slowing the speed of other vehicles in the flow, which is one of the reasons for frequent congestion on city streets (Cao & Sano, 2012). Road capacity is important because it affects traffic planning, design, operation, and financial resource allocation. Passenger car units (PCU) convert the traffic streams into equivalent traffic streams of passenger cars. PCU was initially defined as "the number of passenger cars displaced in the traffic flow by a truck, bus, or dual-tired vehicle under the specific roadway and traffic conditions" in the Highway Capacity Manual (Highway Research Board, 1965). However, in Southeast Asian countries like Nepal, where motorcycles dominate the majority of road vehicles, it would be more reasonable to consider them as the primary vehicle in traffic flow. Measuring traffic capacity on mixed-traffic roadways is a difficult task. Determining road capacity using a standard Motorcycle Equivalence Unit (MEU) that reflects urban roads with a large proportion of two-wheelers would be preferable to traditional PCU-based figures.

2.Objectives

The primary objective of the research was to determine the Motorcycle equivalent unit and the roadway capacity of specific road sections of Kathmandu Valley. The specific objectives of the study were:

1. To determine the relationship between speed and effective space for different classes of vehicles.
2. To identify MEU values for the different vehicle classes.
3. To determine the relationships between traffic flow, traffic density, and mean stream speed of the road segment and determine the capacity of the road using proposed motorcycle equivalent units.

3.Literature Review

This concept of PCU is applied to homogeneous traffic conditions, prevalent in developed nations. For mixed traffic, the passenger car unit (PCU) or passenger car equivalent (PCE) concept came into existence to convert vehicle counts to an equivalent passenger car flow. In mixed traffic conditions where vehicles do not comply with traffic lanes, the required space is expressed by an area (Chandra & Kumar, 2003). Chandra and Kumar (2003) proposed a formula for calculating PCU, incorporating speed as a significant factor in determining the relative effect of individual vehicles on the traffic stream.

$$PCU_i = \frac{\frac{V_c}{V_i}}{\frac{A_c}{A_i}} \qquad \text{(Equation 1)}$$

where, Vc, Vi = Mean speed for cars and type “i" vehicles

Ac, Ai = respective projected rectangular area (length × width) of roads.

The Motorcycle equivalent unit (MEU) is the maximum number of motorcycles that can be replaced by a single vehicle of a particular type running at that vehicle's speed. Minh et al. (2005) conducted a comprehensive analysis of motorcycle behavior and operation in Hanoi, Vietnam. They chose four locations with a high proportion of motorcycles and used videotaping to observe the highways. The MEU values for bicycles, cars, minibusses, and buses were calculated as 1.66, 3.73, 10.04, and 19.96, based on the speed-flow relationships generated for all locations. However, the formula for calculating MEU provided by (Minh, et al., 2005) was similar to that of (Chandra & Kumar, 2003). Minh et al. (2010) established a relationship between dynamic characteristics such as speed and effective space for each vehicle class in three locations in Hanoi City, Vietnam. Effective space is the room or space a vehicle needs to maintain its desired speed. It is determined by multiplying the effective width by the effective length. Data were acquired using the videography method, and SEV software was utilized to analyze the data. However, the MEU values were calculated using a formula based solely on the vehicle's speed. The MEU values for bicycles, cars, minibusses, and buses were 0.97, 2.31, 3.77, and 7.27, respectively. Nataatmadja et al. (2014) used an effective space approach to evaluate the value of MEU on two highways in Jakarta, namely Raya Lenteng Agung Barat and

Teuku Nyak Arief Street. They employed a technique similar to (Minh, et al., 2010) to conduct their analysis. The findings revealed a strong correlation between speed and effective space.

Cao & Sano (2012) investigated the capacity and methodology for MEU in mixed traffic flow by considering the vehicle characteristics such as velocity and effective space on two, three, and four lanes per traffic direction on roads in Hanoi, Vietnam. It was assumed that the lateral width of the subject vehicle is a function of the lateral width of the motorcycles and the total physical size of the subject vehicle and motorcycles. A strong correlation was seen between speed and effective space, with bicycles having the lowest influence due to their preference for the lane nearest to the pavement edge. The MEU values for cars, buses, minibusses, and bicycles were determined to be 3.4, 10.5, 8.3, and 1.4 respectively, using (Equation 2). The critical traffic density levels for four-, three-, and two-lane roads correspond to a maximum traffic flow of 24,335, 21,725, and 13,358 motorcycles per hour, respectively.

$$MEU_k = \frac{V_{mc}}{V_k} \times \frac{S_k}{S_{mc}} \qquad \text{(Equation 2)}$$

where MEUk = MEU of type k vehicle, Vmc, Vk = mean speed (m/s) of motorcycles and type k vehicle

Smc, Sk = mean effective spaces (m2) for motorcycles and type k vehicles, respectively.

Shrestha (2016) investigated the characteristics of motorcycle traffic streams in Kathmandu Valley using videotaping techniques at three mid-block sections. Using the determined MEU values from Table 1, the linear model was used to represent the relationship between speed and flow. To calculate MEU, the formula provided by (Chandra & Kumar, 2003) was used. Neupane (2020) estimated the MEU at different intersections in Kathmandu Valley using the multiple linear regression method. The result showed that the saturation flow rate for vehicles was 7,625 motorcycles per hour per lane, while for right-turning vehicles it was 6,492 motorcycles per hour per lane.

Table 1. MEU values from vehicle class, source: (Shrestha, 2016)

Section	MEU for Vehicle Type				
	Cycle	Motorcycle	Car	Mini Bus	Bus
1	1.46	1	5.29	13.22	27.1
2	1.35	1	5.21	12.61	26.32
3	1.08	1	4.92	12.6	26.49

Based on Cao & Sano (2012), Vyas et al. (2021) developed a modified effective area approach methodology to calculate the MEU values in mixed traffic flow in Ahmedabad, India, by accounting for the speed of adjacent motorcycles in the form of speed ratios to calculate the effective area for the subject vehicle at a given speed. The MEU obtained for cars, motorcycles, rickshaws, buses, light commercial vehicles (LCVs), and bicycles were 3.06, 1.00, 1.88, 9.90, 6.25, and 2.10, respectively. The effective space is affected by the vehicle's speed, the vehicle itself, and the presence of neighboring vehicles. To estimate effective space, Vyas et al. (2021) used samples of vehicles surrounded by motorcycles. The results can be seen in Figure 1.

$$\text{Effective space } (S_e) = L_e \times W_e \qquad \text{(Equation 3)}$$

where Le = Effective length (m), We = Effective width (m)

It was challenging to estimate the effective dimensions of the vehicle while it was moving in traffic. The study calculated the effective space at a specific point in time, which refers to the space occupied by a vehicle under static conditions. Cao & Sano (2012) stated that the size of the vehicle and the motorcycles running to its right and left influence the occupied space of a vehicle.

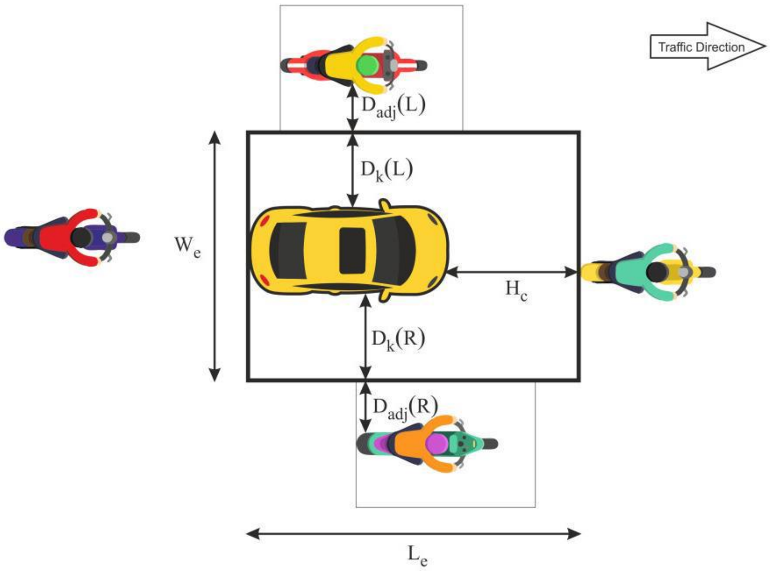

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Figure 1. Effective Space; Source: (Vyas et al., 2021)

$$\text{Effective length } (L_e) = \text{Projected length (L)} + \text{Headway clearance } (H_c) \qquad \text{(Equation 4)}$$

$$\text{Effective width } (W_e) = D_k \text{ (R)} + D_k \text{ (L)} + \text{Width of vehicle (W)} \qquad \text{(Equation 5)}$$

where Dk (R or L) = Right or left lateral clearance width of vehicle type k (m)

The lateral width of the subject vehicle was calculated using the formula represented by (Equation 8).

$$D = D_k + D_{adj} \qquad \text{(Equation 6)}$$

$$D_{adj} = \frac{D}{\left(\frac{L_k \times W_k}{L_{adj} \times W_{adj}} + 1\right)} \qquad \textit{(Equation 7)}$$

$$D_k = D - \frac{D}{\left(\frac{L_k \times W_k}{L_{adj} \times W_{adj}} + 1\right)} \qquad \textit{(Equation 8)}$$

where D = total lateral width (m)

Dk = right or left lateral clearance width of vehicle type k (m)

Dadj = lateral clearance width of neighboring motorcycles (m)

Lk, Wk = physical length and width of subject vehicle (m)

Ladj, Wadj = physical length and width of adjacent motorcycles (m)

For the study, the average length and width of different vehicles were considered according to Indo-HCM (2017). Using videography, different vehicle brands were classified based on their average area due to non-uniformity in their sizes. The dimensions of all vehicles were obtained from various automobile websites.

The capacity of the road is highly influenced by lane discipline, various maneuver activities, and the static and dynamic properties of vehicles in mixed traffic. To determine the roadway capacity, Tiwari & Marsani (2014) investigated various conventional macroscopic speed-density models such as Greenshields, Greenberg, Underwood, Drake, Pipes-Munjal, Polynomial, and Modified Drake and Underwood models that were suitable in the context of Nepalese roads, specifically in the Jadibuti-Suryabinayak road section. Based on goodness of fit (R2 value and standard error), the conventional Underwood model was chosen as the best-fit model for the road stretch. Gautam (2020) examined the macroscopic speed-density models for the Balkhu-Sanepa section of the ring road. He found that the Underwood-Taylor series model provided the best fit with reasonable estimates of free flow speed and density.

Traffic flow fundamental relations refer to the relationship between the three vital elements: speed, volume, and density. Density is referred to as the number of vehicles occupying a specific lane or stretch of road and is typically stated in terms of vehicles per km (veh/km). Estimation of density in the field directly is challenging, but it can be achieved through aerial photography, videography, or viewing substantial sections of highway. It is more typically derived from an equation if the speed and rate of flow are known.

Table 2. Vehicle classes assumed and classified with dimensions

Vehicle Type	Length (m)	Width (m)	Projected Area (sq.m)	Vehicles considered/classified in this study
Standard car (SC)	3.72	1.44	5.36	Maruti Suzuki 800 DX, Suzuki alto 800 STD, Maruti S-Presso, Fiat 500, Santro Xing
Big car (BC)	4.58	1.77	8.11	Hyundai i-10, Kia picante, Wagon R, Volkswagen up, Fiat Panda, Toyota Aygo, Suzuki swift, Ford Figo, Honda Jazz, Honda, Mazda 2, Kia Rio, Hyundai i-20, Volkswagen Polo, Creta, Mahindra Scorpio, Hyundai Tucson, Tata safari, Landcruiser Prado, Isuzu D-max, Toyota Hilux
Motorized two-wheeler (TW)	1.87	0.64	1.2	Vespa SXL 125, Hero Pleasure Plus, Honda Dio 100 CC, VS NTORQ 125, Yamaha Ray ZR, Yamaha R15, Hero Super Splendor, TVS Apache RTR 180, Pulsar 220F, Honda Shine 125, Pulsar 150 CC, Yamaha FZ-s, Honda unicorn, Suzuki Gixxer
Utility vehicles	4.2	1.7	7.14	Mahendra Bolero, Tata Pickup, Tata Ace
Minibus (MB)	6	2.43	14.58	Mahindra Tourister Excelo (15), Tata City ride School, Eicher Starline 2050 C, Nepal yatayat, Kirtipur yatayat, Eicher 10.75H skyline bus
Bus (B)	10.1	2.43	24.54	Eicher Skyline 2112 M Bus, Eicher 10.75H skyline school bus (32), Tata LP 712, MITR School Bus, Mahindra Tourister Excelo (25), Ashok Leyland Lynx, Ashok Leyland Oyster Tourist Bus
Light commercial vehicles (LCV)	6.1	2.1	12.81	Blue Micro, Hiace, Jumbo Hiace, Force Tempo Traveler 3050
Two / Three Axle trucks (TAT) – gross weight up to 25.2 tonnes	7.5	2.35	17.63	Tata 407, Eicher Pro 2049, Tata 709, Eicher 14 ft, Tata Truck (6 Tire), Eicher 19, Tata Taurus (12 Tire), Tata 10-wheeler
Multi-axle trucks (MAT) – gross weight of more than 25.2 tonnes	12.1	2.44	29.52	Bharat Benz 2823C, Tata Taurus (14 Tire), Container 32 SXL, Open Trailor (ODC), Open Trailor (ODC)

$$q = v * k \quad \text{(Equation 9)}$$

where q = rate of flow (veh/hr), v = average travel speed (km/hr), k = average density (veh/km)

To overcome Greenberg's model's drawbacks, Underwood (1961) proposed the exponential model as represented by (Equation 10).

$$V = V_f \times e^{-\frac{k}{k_j}} \quad \text{(Equation 10)}$$

where V = speed corresponding to density k, Vf = free flow speed, kj = optimum density (density at capacity)

The limitation of this concept is that speed becomes zero only when the density reaches infinity. As a result, it cannot be used to estimate speeds at high densities.

4.Methodology

4.1.Data Collection and Analysis

The study focused on two urban mid-block sections of the Kathmandu Valley, specifically the Gatthaghar-Kaushaltar and Balkumari-Gwarko segments. A pilot speed study was conducted at both locations to define the trap length. A standard trap length of 30m was used to obtain the speed and effective space data. The Gatthaghar-Kaushaltar segment is a four-lane, divided two-way sub-arterial road with a total width of 10 meters per direction. Similarly, the Balkumari-Gwarko segment has eight lanes, consisting of two independent two-way two-lane roads plus a separate two-lane service lane per direction. For this study, only lanes with traffic directions from Kaushaltar to Gatthaghar and Gwarko to Balkumari were considered. Video footage of traffic passing the strip was taken from the roof of a tall building for two sites on September 5–7, 2022, and September 12–14, 2022, from 8:30 a.m. to 10:30 a.m. and 4:30 p.m. to 6:30 p.m., respectively, for three consecutive regular working days in dry weather to analyze the peak hour flow. The video was played later on a larger screen using SEV software, as shown in Figure 2. SEV software was developed in the lab to analyze the traffic data as described in (Minh, et al., 2010). The software is capable of measuring the position of vehicles over various intervals of time, as well as the trajectories of several vehicles at the same time. Initially, four base points along the road stretch were marked to obtain speed and distance readings for each sample vehicle. In the software, vehicles were instantly assigned as subjects or surrounding vehicles by hovering and right-clicking the mouse. The samples were vehicles surrounded by motorcycles on their front, left, and right sides. Additionally, the software converts the screen coordinates into roadway coordinates. The speed data and coordinates of the vehicles were extracted after they entered and left the trap length. The converted screen coordinates were used to determine the effective space. The measurements can be repeated multiple times to ensure accuracy. For every 1-second interval, as desired, the speed of each sample vehicle was calculated and averaged out until the vehicles left the trap length. The data was generated in Excel format, which was used to calculate speed and effective space for different vehicle classes. To determine the traffic volume and types of vehicles on the road, the number of vehicles was counted manually.

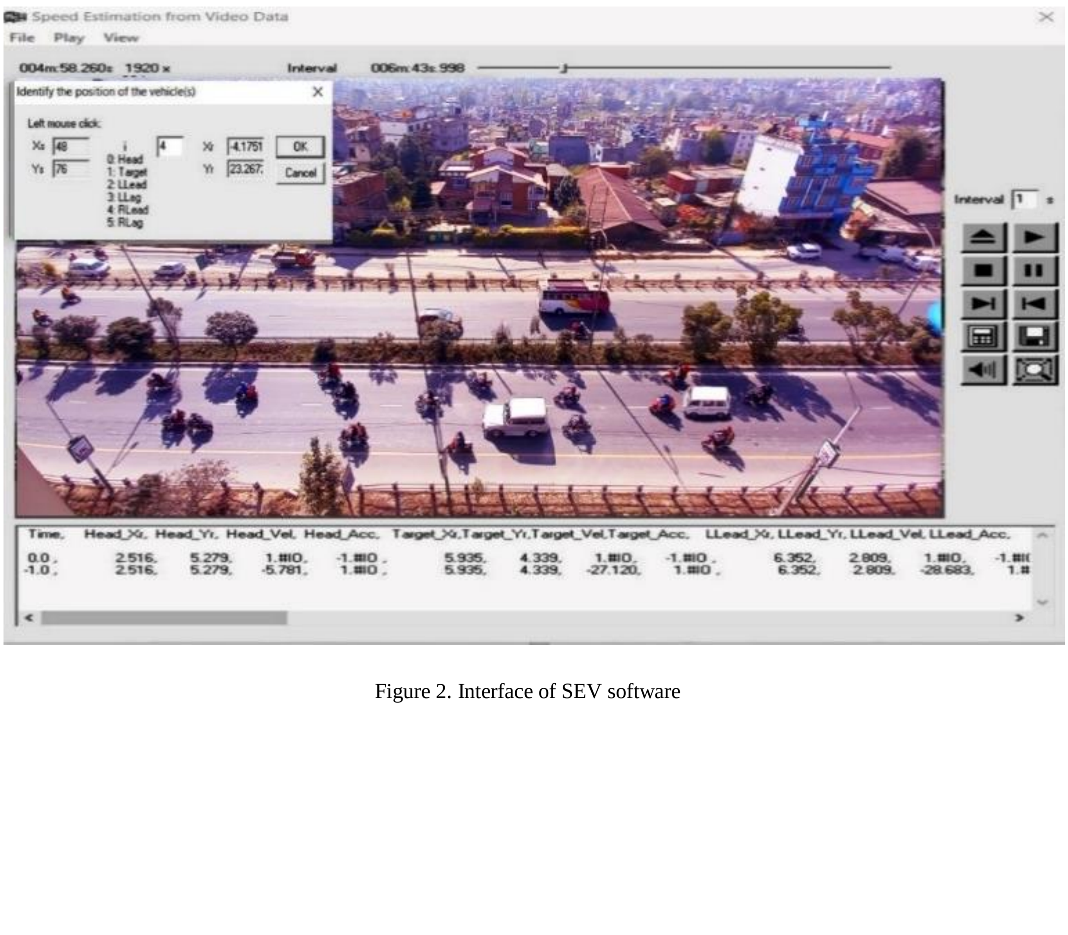

Figure 2. Interface of SEV software

After calculating other necessary parameters in an Excel spreadsheet, effective space, and MEU values were computed for various vehicle classes using (Equation 3) and (Equation 2) given by Cao & Sano (2012). To calculate the capacity, traffic volume samples were recorded every minute in an Excel spreadsheet. The data was then organized into 15-minute intervals and converted into the equivalent flow rate in motorcycles per hour. The traffic density was calculated using (Equation 9) for each 15-minute interval of data. Underwood's exponential model was used to estimate roadway capacity. The standard t-test was used to validate the calculated roadway capacity. The DoR (2022) traffic survey was used as a reference to allocate the sample into different vehicle classes. To determine the minimum sample size (MEU), 400 samples were selected using Krejcie and Morgan's (1970) formula. The samples were split into two sections, with samples falling within the trap length and surrounded by motorcycles. A purposive sample was carried out, and vehicle classes were classified according to Indo-HCM (2017). Due to the small number of trucks in the study area, only five truck samples of each kind were collected as a minimum sample size. To calculate roadway capacity, 10% of the total volume of each observed vehicle class in a 15-minute interval was considered (Tiwari & Marsani, 2014; Gautam, 2020).

5.RESULTS AND DISCUSSIONS

5.1.Relationship between speed and effective space for different classes of vehicles.

The Gatthaghar-Kaushaltar segment showed a dominant two-wheeler presence (78.25%), followed by cars (12.98%), buses (3.60%), utility vehicles (2.97%), trucks (1.24%), and LCVs (0.97%). Similarly, in the Balkumari-Gwarko segment, two-wheelers dominated (71.60%), followed by cars (18.52%), utility vehicles (4.40%), buses (3.16%), trucks (1.73%), and LCVs (0.59%) as shown in **오류! 참조 원본을 찾을 수 없습니다.**3. The Gatthaghar-Kaushaltar segment recorded a maximum volume of 3,064 vehicles per hour per direction in the morning and 5,490 vehicles per hour per direction in the evening, with peak hours of 9:30 to 10:30 a.m. and 5:00 to 6:00 p.m., respectively. In this segment, the AADT was 1,14,375 vehicles per day. The Balkumari-Gwarko segment had a volume of 3,888 vehicles per hour per direction, with peak hours of 9:00 a.m. to 10:00 a.m. and 5:00 p.m. to 6:00 p.m. The AADT in this segment was 97,200 vehicles per day.

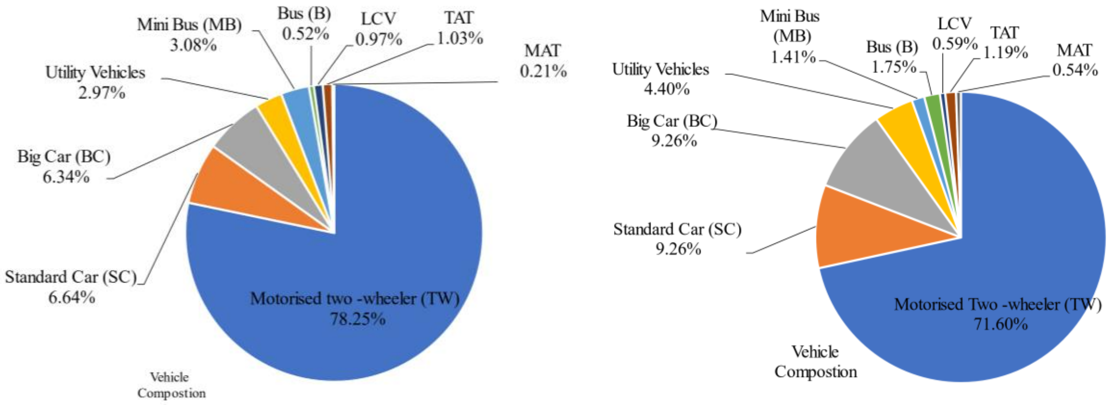

Figure 3. Vehicle composition at Gatthaghar - Kaushaltar and Balkumari-Gwarko section

To determine the relationship between mean speed and mean effective space for different vehicle classes, data collected from the field was used to plot different models and determine the best curve fit. The Gatthaghar-Kaushaltar segment showed a strong correlation (r = 0.718) between motorcycle speed and effective space. Based on the obtained R2 = 0.516 value for two-wheelers, the quadratic model was used for the study. The ANOVA test performed to justify the relationship between the speed of the subject vehicle and effective space using the quadratic model was found to be significant. Similarly, the model was used for other vehicle classes, too.

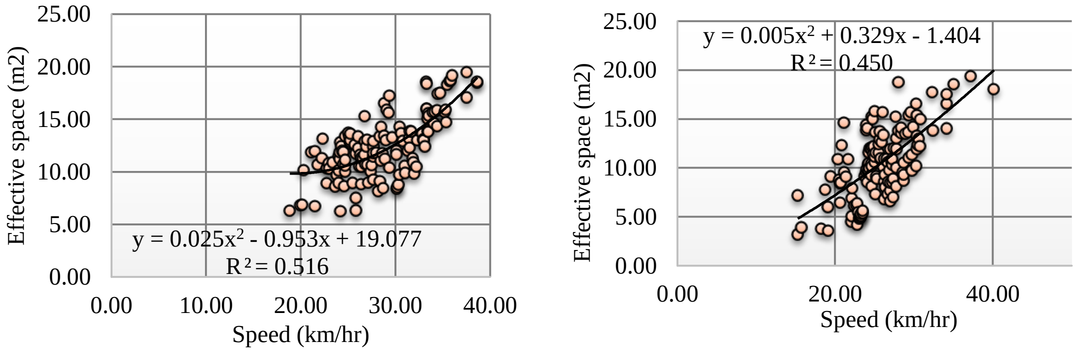

Figure 4. Relationship between speed and effective space of Motorcycles, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

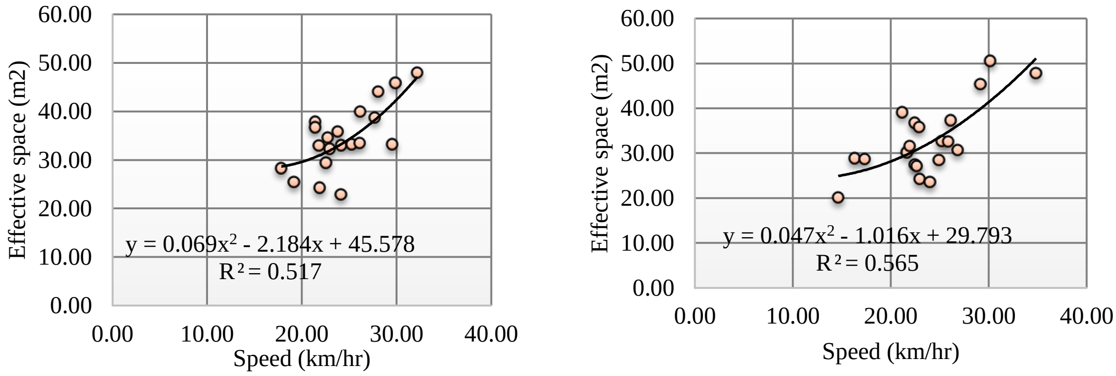

Figure 5. Relationship between speed and effective space of Standard car, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

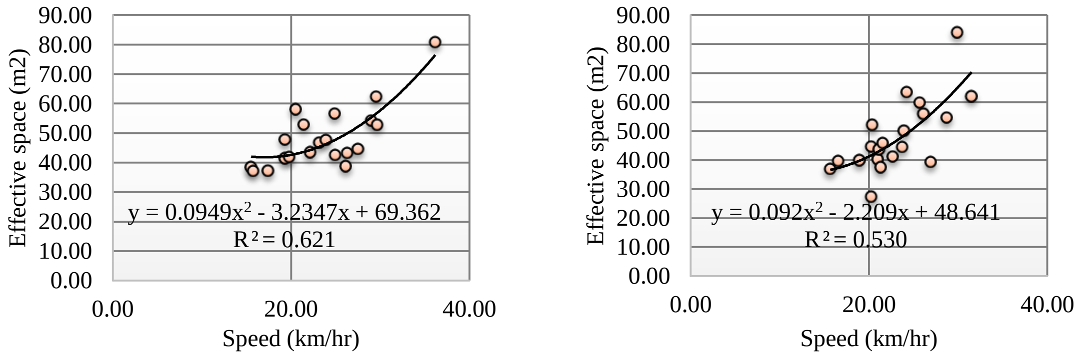

Figure 6. Relationship between speed and effective space of Big car, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

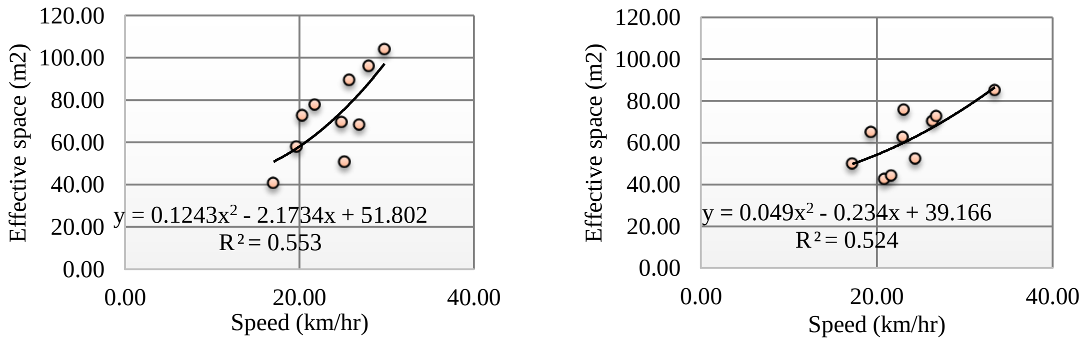

Figure 7. Relationship between speed and effective space of LCV, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

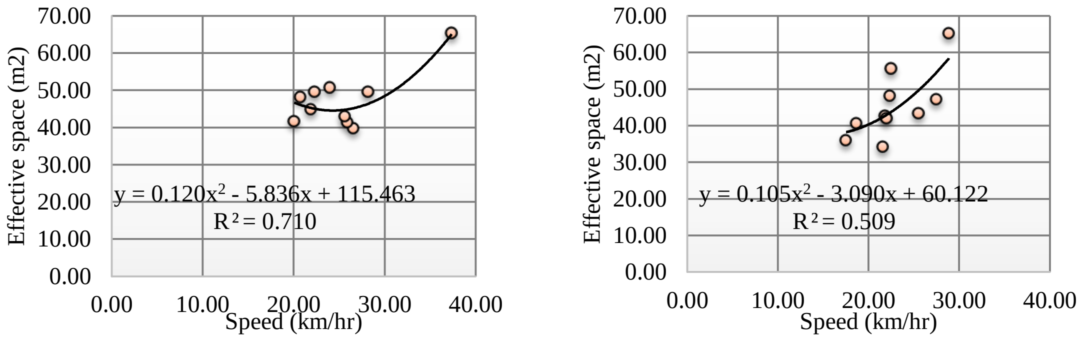

Figure 8. Relationship between speed and effective space of Utility vehicle, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

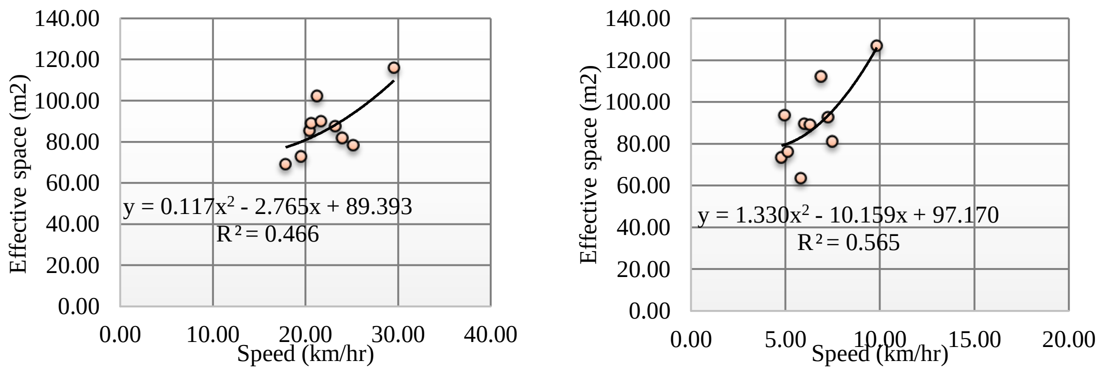

Figure 9. Relationship between speed and effective space of Minibus, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

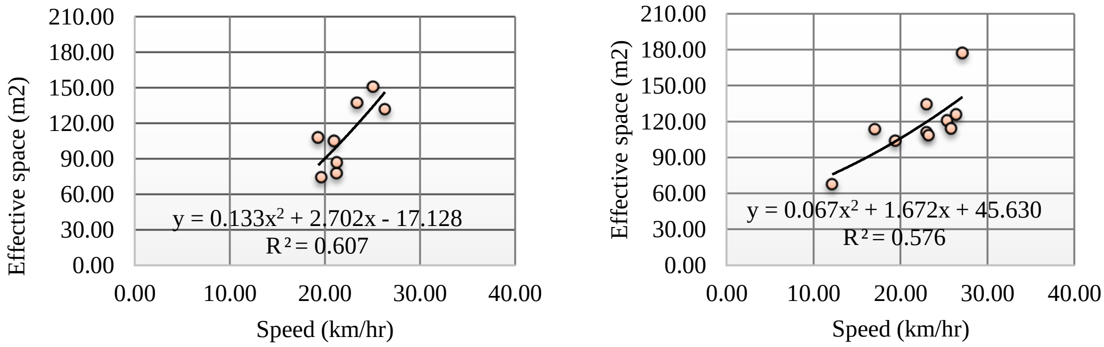

Figure 10. Relationship between speed and effective space of Bus, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

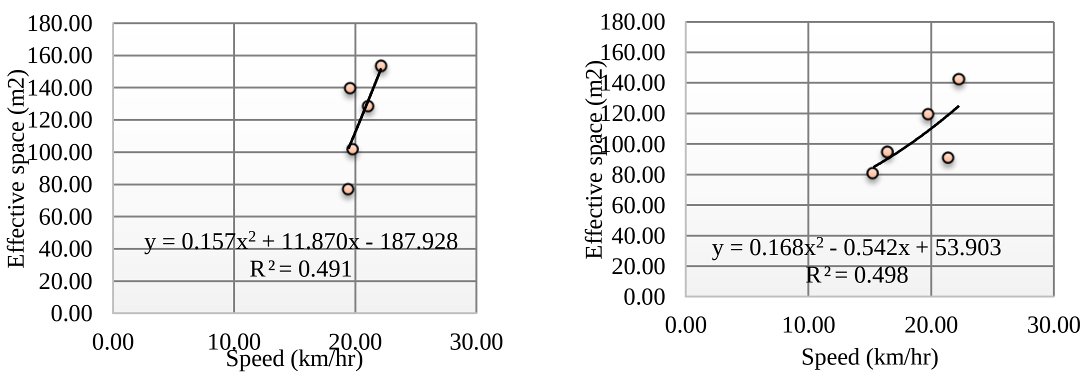

Figure 11. Relationship between speed and effective space of TAT, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

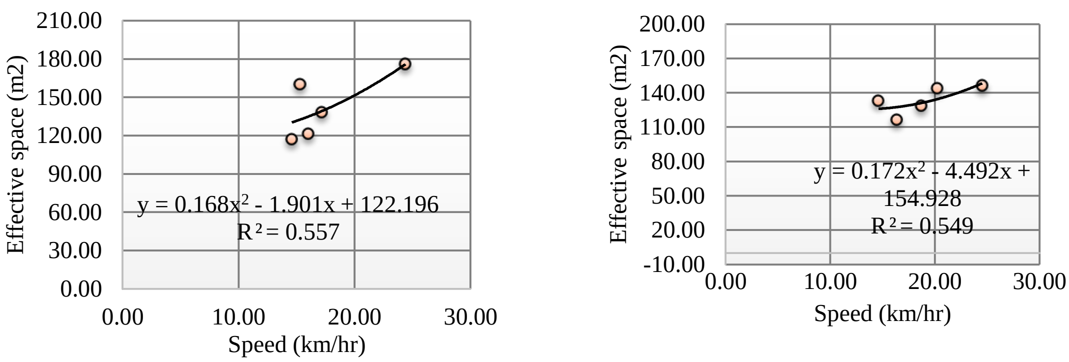

Figure 12. Relationship between speed and effective space of MAT, Gatthaghar - Kaushaltar and Balkumari-Gwarko section

The quadratic relationship for both locations (Figure 4 to Figure 12) used to demonstrate the relationship between speed and the effective space of a vehicle; it can be seen that the R2 value was high for different vehicle classes. The graph of the subject vehicle's speed versus effective space was generated using MS Excel software. It has been demonstrated that the speed at which a vehicle travels on a road affects the amount of space it effectively occupies. Specifically, as a vehicle's speed increases, so does the area of effective space it occupies on the road. Conversely, as a vehicle's speed decreases, the area of effective space it occupies also decreases. This relationship is important to consider when analyzing traffic flow and safety on roads. It illustrated that speed was a significant factor that influenced vehicles’s effective space. When a vehicle's speed increases on a road, its area of effective space also increases. Conversely, this area decreases as the subject vehicle travels at a slower speed.

5.2.Determination of MEU values for the different vehicle classes

MEU values for all the vehicle classes considered in this study were calculated using (Equation 2) based on the values of speeds and effective spaces from both locations. The results showed that the MEU values vary depending on the average speed ratios of motorcycles and other vehicles. The observed number of samples for each vehicle type was unique. The study used a weighted mean method to calculate the unique MEU value for each vehicle type at different locations.

Table 3. Results of Motorcycle Equivalent Units of vehicles from the proposed model

Subject Vehicle	Parameters	Location 1	Location 2	Weighted Mean MEU
Two-wheelers - motorcycle	V_{mc}	7.92	7.16	
	S_{mc}	12.37	10.54	
	MEU_{mc}	1	1	1
	Sample size	136	136	
Standard car (SC)	V_k	6.79	6.58	
	S_k	34.48	32.93	
	MEU_{scar}	3.25	3.4	3.32
	Sample size	20	20	
Big car (BC)	V_k	6.57	6.4	
	S_k	48.39	48.1	
	MEU_{bcar}	4.72	5.11	4.91
	Sample size	20	20	
Utility vehicles	V_k	7.02	6.34	
	S_k	47.39	45.49	
	$MEU_{utility}$	4.32	4.87	4.6
	Sample size	10	10	
Minibus (MB)	V_k	6.2	6.45	
	S_k	87.14	89.77	
	$MEU_{mini\ bus}$	9	9.45	9.22
	Sample size	10	10	
Bus (B)	V_k	6.15	6.18	
	S_k	108.91	117.62	

Subject Vehicle	Parameters	Location 1	Location 2	Weighted Mean MEU
	MEU_{bus}	11.34	12.93	12.22
	Sample size	8	10	
Light commercial vehicles (LCV)	V_k	6.64	6.56	
	S_k	72.7	62.05	
	MEU_{LCV}	7.01	6.43	6.72
	Sample size	10	10	
Two / three axle trucks (TAT)	V_k	5.66	5.28	
	S_k	120.03	105.57	
	MEU_{TAT}	13.57	13.58	13.57
	Sample size	5	5	
Multi-axle trucks (MAT)	V_k	4.85	5.25	
	S_k	142.51	133.44	
	MEU_{MAT}	18.8	17.28	18.04
	Sample size	5	5	

Table 3 shows that the MEU values of motorcycles, standard cars, big cars, utility vehicles, minibusses, buses, light commercial vehicles, two- or three-axle trucks, and multi-axle trucks are 1.000, 3.320, 4.910, 4.650, 9.220, 12.220, 6.720, 13.570, and 18.040, respectively. This research does not take into account various factors such as driver characteristics, road geometry, and other local traffic conditions that may affect the effective space of subject vehicles.

Table 4. Comparison of MEU values to previous studies

Model	Cars		Mini Bus (MB)	Bus (B)	LCV
	Standard Car (SC)	Big Car (BC)			
Proposed Model	3.32	4.91	9.22	12.22	6.72
(Minh, et al., 2005)	3.73		10.04	19.96	-
(Minh, et al., 2010)	2.31		3.77	7.27	-
(Cao & Sano, 2012)	3.4		8.3	10.5	-
(Shrestha, 2016)	5.14		12.81	26.64	
(Vyas, et al., 2021)	3.06		-	9.9	6.25

In previous studies by Minh et al. (2005) and Shrestha (2016), the MEU values were determined based on the speed and area of the subject vehicle, as mentioned (Chandra & Kumar, 2003). However, in Minh et al.'s (2010) study, the MEU values were calculated based on the mean speed of the subject vehicle, ignoring the mean speed of motorcycles in the traffic flow. Cao and Sano (2012) improved upon these limitations by considering the dynamic characteristics of moving vehicles. The proposed model provided MEU values that were similar to those obtained by Vyas et al. (2021) and Cao and Sano (2012) for different classes of vehicles. For instance, the estimated MEU values for buses were 12.220, 10.500, and 9.900, respectively, with a standard deviation of 0.98. However, the standard deviation of MEU values obtained from the proposed model and Shrestha's (Shrestha, 2016) model was found to be 7.21.

5.3.Estimating road capacity using proposed motorcycle equivalent units (MEU)

Three scatter diagrams were obtained for three relationships: speed-density, flow-speed, and flow-density. The curves are monotonically decreasing and have simpler mathematical forms than the other two curves. Therefore, the initial calibrations focused on the relationships between speed and density. Speed-density curves act as the most basic interface between drivers and other road users. Drivers adjust their speed according to their perception of other vehicles' proximity (density). Flow is a product of speed and density.

5.3.1. *Model Calibration*

The extracted data was used to calibrate the conventional Underwood's exponential. Table 5 shows the values of free-flow speed (Vf), density at maximum flow (Kj), speed at maximum flow (Vmax), capacity (qmax), and goodness of fit (R2 value). The extreme points in Figure 13 and Figure 14 represent the optimum density or density corresponding to maximum flow (Kj) for the Morning and Evening of the two locations.

Table 5. Calibrated Conventional Underwood's Exponential Model

Location	Time	Calibrated Equation	V_f km/hr.	K_j (motorcycles /km)	V_{max} km/hr.	R^2	q_{max} (motorcycles/ hr. /traffic direction
Gatthaghar - Kaushaltar	Morning	$V = 47.546\, e^{-\frac{K}{591.716}}$	47.546	591.716	17.491	0.742	10,350
	Evening	$V = 49.958\, e^{-\frac{K}{671.141}}$	49.958	671.141	18.379	0.736	12,335
Balkumari - Gwarko	Morning	$V = 41.435\, e^{-\frac{K}{1137.659}}$	41.435	1137.659	15.243	0.75	17,341
	Evening	$V = 37.832\, e^{-\frac{K}{1479.29}}$	37.832	1479.29	13.918	0.729	20,589

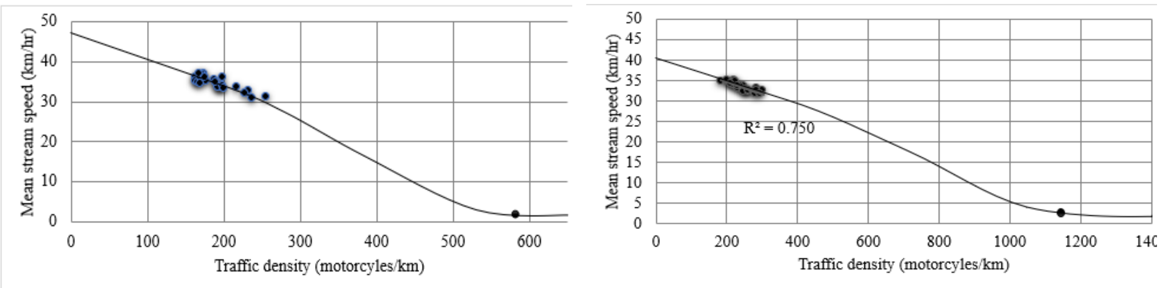

Figure 13. Calibration of Underwood model, Gatthaghar - Kaushaltar and Balkumari-Gwarko section (Morning)

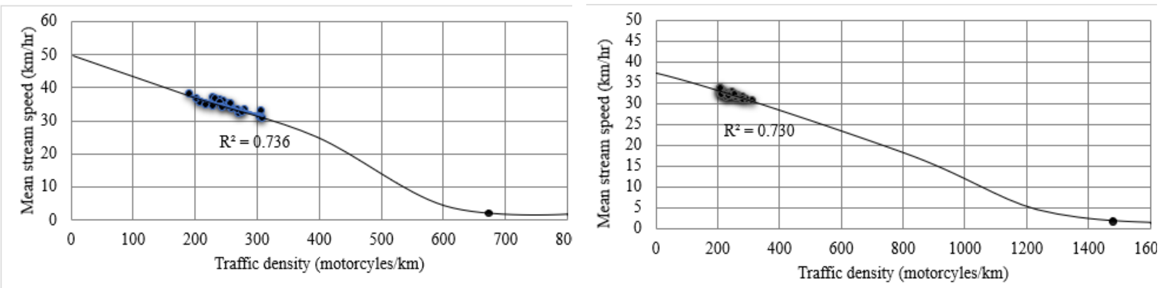

Figure 14. Calibration of Underwood Model, Gatthaghar - Kaushaltar and Balkumari-Gwarko section (Evening)

The Underwood model demonstrated the exponential relationship between speed and density. The free flow speed and density corresponding to the maximum flow as $\frac{dq}{dK} = 0$ and the roadway capacity for both locations is listed in Table 6.

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5.3.2 Model Validation

To validate Underwood's exponential model, two hours of videography data were collected on November 27th and 28th, 2022, in both morning (8:30 a.m. to 10:30 a.m.) and evening (4:30 p.m. to 6:30 p.m.) time frames at two different locations. The first step involved checking the goodness of fit of the calibrated model based on validation data. In the second step, the model was recalibrated and their corresponding goodness of fit, density at capacity, speed at capacity, and free flow speed were analyzed. The recalibrated model was validated using the observed field density, speed, and predicted speed data from the recalibrated equation. An assumption was made for null hypothesis testing which stated that the difference between actual and predicted speed was zero, with an alternative hypothesis that the difference was not zero. The t-statistical test was used to validate various speed, flow, and density parameters. To estimate the t-statistics, p, and t-critical values at a 95% confidence level, the standard t-distribution table was used.

Table 6. Recalibrated conventional Underwood model based on validation data

Location	Time	Recalibrated Equation	R^2	t_{value}	$t_{critical}$	$P_{value} > 0.05$
Gatthaghar - Kaushaltar	Morning	$y = 47.575 \times e^{-\frac{K}{600.276}}$	0.964	0.842	2.365	0.444
	Evening	$y = 47.579 \times e^{-\frac{K}{753.069}}$	0.951	1.329	2.365	0.237
Balkumari - Gwarko	Morning	$y = 42.756e^{-\frac{K}{942.507}}$	0.817	0.858	3.182	0.437
	Evening	$y = 37.819 \times e^{-\frac{K}{1457.726}}$	0.884	1.092	2.365	0.338

The t-statistical value in each case was lower than the t-critical value, and the P-value was greater than the level of significance (i.e., P value >0.05). As a result, it failed to reject the null hypothesis, meaning there was no significant difference between actual and predicted speed i.e. the difference between actual and predicted speed was zero. This confirmed the validity of Underwood's exponential model for the given field data.

6.Conclusion And Recommendation

The purpose of the research was to determine the motorcycle equivalent units (MEU) of different vehicles and roadway capacity in Kathmandu Valley. The study used field data from two urban mid-block road sections. The research found a strong correlation between speed and the effective space of all vehicles. Speed was a significant factor that influenced vehicle effective space. The study calculated MEU values for different types of vehicles, including motorcycles, standard cars, big cars, utility vehicles, minibusses, buses, light commercial vehicles, two- or three-axle trucks, and multi-axle trucks. The MEU values were 1, 3.32, 4.91, 4.65, 9.22, 12.22, 6.72, 13.57, and 18.04, respectively. The MEU values were similar to those of previous studies in developing countries with mixed traffic but significantly different from those in Nepal (Shrestha, 2016). The study plotted diagrams for traffic flow, traffic density, and mean stream speed. It revealed that road capacity depended on traffic volume, and density varied over time. The maximum capacity of the Gatthaghar-Kaushaltar segment was 12,335 motorcycles/hr./traffic direction in the evening, while the Balkumari-Gwarko section had 20,589 motorcycles/hr./traffic direction. The maximum amount of motorcycle equivalent traffic was observed during the evening.

The research suggests using the effective space methodology to determine motorcycle equivalent units on-road sections. It also recommends using the Underwood exponential model to study traffic speed, flow, density, and road capacity. However, the study's limitations include the ability to determine MEU values through a video in software with limited parameters under time constraints. The study also suggests considering additional factors such as driver characteristics, gender, age, income, road geometry, and local conditions that affect the effective space. It also recommends determining the road section's level of service using MEU.

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