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CAPACITY ANALYSIS AT URBAN UNCONTROLLED INTERSECTIONS UNDER MIXED TRAFFIC CONDITIONS: A CASE STUDY IN WARANGAL CITY

Summary. The performance of the road network depends on the capacity of the intersection in the area. Estimation of capacity becomes difficult under mixed traffic conditions where different types of vehicles share common space without following priority rule. Yield- controlled and stop sign-controlled intersections operate similarly to uncontrolled intersections in India due to lack of respect for priority rules and lane discipline. The current study estimated capacity using critical gaps based on the HCM methodology and examined the relationship between occupancy time and capacity. Aiming to develop a model to estimate capacity directly from occupancy time. Five three-legged uncontrolled intersections were selected and data were acquired through a video camera. The occupation time and gap data were extracted manually and the effect of various geometric and traffic parameters like median width, conflicting flow, proportion of heavy vehicles in the conflicting flow, and pedestrian flow on extracted occupation time using correlation and regression analysis was studied. The results of the study stated that with a 5% increase in conflicting flow occupation time was increased by 0.2 sec

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and with a 1% increase in heavy vehicles in conflicting flow, occupation time increased by 0.35 sec, and for a 5% increase in pedestrian volume the occupation time of minor approach is increased by 0.13 sec. Two-wheelers and Three-wheeler vehicles had the least critical gap and the highest was observed for heavy vehicles. Capacity was found to decrease with an increase in occupation time. A linear regression model was developed to estimate capacity using occupation time. This paper can provide a better understanding of the occupation time and its effect on movement capacity.

Keywords: traffic flow, capacity analysis, regression analysis, uncontrolled intersection, mixed traffic condition

1. INTRODUCTION

The overall performance of the roadway network is heavily dependent on the capacity of the intersections. An intersection is a shared area where two or more roads cross, making the shared area a potential conflicting zone. According to the Highway capacity manual (HCM, 2010) capacity is defined as the maximum hourly rate at which vehicles are expected to pass through a section or a point of a roadway under prevailing conditions [1]. In India, the presence heterogeneous traffic with differing speeds makes the intersections highly complex. The lack of lane discipline further complicates the accurate estimation of intersection capacity. The traditional capacity estimation models designed for homogeneous traffic conditions where priority rules are strictly followed, these methods often underestimate the capacity when applied to Indian conditions. The need to accurately estimate the capacity of uncontrolled intersection under mixed traffic conditions is critical as the majority of existing methods fall short in such conditions. The motivation behind this study arises from the recognition that current methodologies do not adequate reflect the complexities of Indian traffic. The objective of this study is to address the gaps by using the concept of occupation time to estimate the capacity of urban uncontrolled intersections. This method is better suited to mixed traffic conditions as it takes into account the actual behavior of vehicles as they navigate the conflict area of an intersection. The study will focus on key traffic parameters such as conflicting flow, the percentage of heavy vehicles, and pedestrian flow, which are known to significantly influence driver behavior and intersection performance.

2. LITERATURE REVIEW

2.1 Studies based on occupation time

Mohan et al. (2018) estimated the critical gap at TWSC intersection based on occupation time data and compared it with Modified Raff method (1950), maximum likelihood method, and the capacity estimated from the critical gap obtained from the occupation time method was found closer to field values [2]. Asaithambi and Anuroop (2016) observed that the occupation time increases with an increase in conflicting flow rate [3]. Ashalatha and Chandra (2011) estimated critical gaps through clearing behavior and observed that forced entry has a substantial effect on minor approach movement capacity [4]. Chandra et al. (2009) analyzed service delay at an uncontrolled intersection, a linear relationship was observed between service delay and conflicting traffic up to conflicting traffic of 0.2 veh/sec after which it had an exponential relationship [5].

2.2 Studies based on the critical gap

Pawar et al. (2022) demonstrated that the accepted gaps can be used as a surrogate safety measure to estimate the crash likelihood at unsignalized T-intersections and validated the approach through statistical modeling and risk characterization, showing a close approximation with actual crash data. [6]. Mohan et al. (2021) investigated the impact of the composition of conflicting traffic flow on critical gaps under mixed traffic conditions. A logarithmic increasing trend was observed between the critical gap and the percentage of heavy vehicles [7]. Duttu and Ahmed (2018) classified minor road drivers of uncontrolled T-intersections as aggressive and non-aggressive based on forcing their entry. A linear regression equation was developed to estimate the critical gap using clearing time and forced gap. The critical gap was found to increase with increasing clearing time [8]. Abhigna et al. (2017) observed that driver behavior, vehicle dimensions, and vehicle performance affect the gap acceptance. Gap offering vehicles in a major approach plays a major role in accepting or rejecting the gap [9]. Amin and Maurya (2015) and Maurya et al. (2016) estimated the critical gap at a four-legged uncontrolled intersection using different methods and found that the clearing behavior methods estimated reasonable results and can be applied for both over-saturated and under-saturated conditions [10, 11]. Patil and Pawar (2014) analyzed the spatial and temporal gap acceptance behavior at four-legged intersections and observed that the critical gaps are less than 4 sec, showing drivers aggressive behavior [12]. Troutbeck (2014) reviewed the maximum likelihood method (MLM) and probability equilibrium method to estimate the mean critical gap using simulation and the observed MLM gives consistent and unbiased estimates irrespective of its assumptions regarding distributions of the critical gap [13]. Kaysi and Alam (2000) developed a simulation model at unsignalized intersections which operate under partial control measures. The model comprises vehicle arriving patterns, resulting gaps, and divergence perception and learning phenomena [14].

2.3 Studies based on capacity

Asaithambi and Aswini (2022) estimated capacity using HCM (2010) and the conflict flow method with high pedestrian flow. The capacity of intersections with high pedestrian flow had 24 percent less compared to no pedestrian flow [15]. Ruskic and Mirovic (2021) estimated the capacity of three-legged unsignalized intersections using simulation software (Simtraffic and Anylogic). Anylogic results in capacity values close to the field capacity as it considers factors like subject vehicle length, acceleration of the vehicle, and speed of the vehicle in major flow [16]. Amaranatha et al. (2018) analyzed the performance of uncontrolled intersections using IRC SP 41 (1994), and observed poor traffic conditions with long traffic delays due to a high percentage of heavy vehicles [17]. Prasetijo et al (2014) found that the occupancy time of the minor approach is higher and is inversely proportional to its capacity [18]. Li et al. (2009) and Shi and Li (2008) determined the movement capacity including the effect of non-motorized traffic and pedestrians which were found to have a significant effect on the capacity [19, 20]. Prasetijo et al. (2005) devised a new method concerning departure headway based on the conflict flow technique. The capacities obtained had a significant effect due to non-motorized traffic and side frictions determined [21]. Chodur (2005) modeled the capacity of unsignalized urban intersections in Poland based on geometric and traffic parameters and found that the size of the city and the number of lanes had a considerable effect on the critical gap [22]. Li et al. (2003) computed the capacity of unsignalized intersections using a probability equation with the function of mixed vehicle groups crossing various conflict areas of intersection. The model predicted reasonable values and also fitted Chinese traffic conditions better [23]. Pollatschek et al. (2002) developed a capacity model based on a risk-reward process. The model indicates that different driver populations exhibit different entry capacities [24]. Brilon and Wu (2001) estimated capacity using the conflict flow technique which overcomes the drawbacks of the gap acceptance method but can be applicable to a specific case with low traffic [25].

From the literature review, it is identified that the capacity for uncontrolled intersection is estimated by different approaches such as gap acceptance models, empirical, conflict techniques, and occupation time analysis. There are different procedures to estimate critical gaps and most of them are modeled for homogenous traffic conditions. Indian traffic conditions are far from homogenous, with varying vehicle types, lack of lane discipline, and priority rules while crossing an intersection area. Therefore, these methods provide an incorrect estimation of the critical gap, which results in an incorret capacity estimation of uncontrolled intersections. Numerous factors such as drivers' age, approach speed, occupancy, waiting time, and conflicting vehicle type were found to show a significant impact on driver behavior when maneuvering in intersection areas. From the above studies, it was identified that the clearing behavior method which uses occupation time for estimation of critical gap suits mixed traffic conditions as it considers actual vehicle behavior while clearing conflict areas of intersection. In the present study, it is planned to use the concept of occupation time for estimating the capacity of an urban uncontrolled intersection concerning prevailing traffic parameters such as conflicting flow, percentage of heavy vehicles, and pedestrian flow.

3. DATA COLLECTION AND DATA EXTRACTION

The data collection for this study was conducted at five different uncontrolled T-intersections, each with three legs. All the five intersections are located in the city Warangal. To gather accurate information, a video camera was set up on a nearby building at each intersection. The placement allowed the camera to capture the entire intersection area, ensuring that all approaches and vehicle movements were clearly visible. For each intersection, data were recorded over a period of six hours focusing on the busy morning and evening hours when traffic was at its peak. The data collection took place on typical weekdays to reflect regular traffic patterns. The specific locations of the intersections studied are shown in Figure 1.

In addition to the traffic data, detailed geometric data about each intersection was also collected, including the number of lanes, whether there were medians on the major and minor roads, and the presence of features such as cycle tracks and shoulders. Precise measurements were taken using a measuring tape and a measuring wheel to determine the width of the lanes, the width and length of the medians, the width of the approaches to the intersection, and the width of any shoulders that were present. These measurements were crucial for understanding the physical layout of each intersection and how it might influence traffic flow and safety. The road geometric details are listed out in Table 1.

The table summarizes that the major lanes are consistently 4-lane divided while minor lanes vary between divided and undivided configurations. Lane widths range between 2 m and 4 m, with median widths present for major lanes but often missing for minor lanes. This absence could impact traffic flow and safety as medians play a critical role in controlling vehicle movement and providing refuge for pedestrian.

I. Dargah intersection

II. Erragattu intersection

III. Madikonda intersection

IV. Neelima intersection

V. Hanamkonda bus stand intersection

Fig. 1. Images of intersections identified

Tab. 1

Geometric details of the intersections

Intersection	No of lanes		Lane width (m)		Median width (m)	
	Major	Minor	Major	Minor	Major	Minor
I	4-lane divided	2-lane divided	3.5	2.5	1.4	1.4
II	4-lane divided	2-lane undivided	3.3	2.25	1.2	-
III	4-lane divided	2-lane undivided	4	2	2	-

IV	4-lane divided	2-lane undivided	3.3	3	1.1	-
V	4-lane divided	2-lane undivided	2.25	2	0.6	-

4. FIELD DATA ANALYSIS

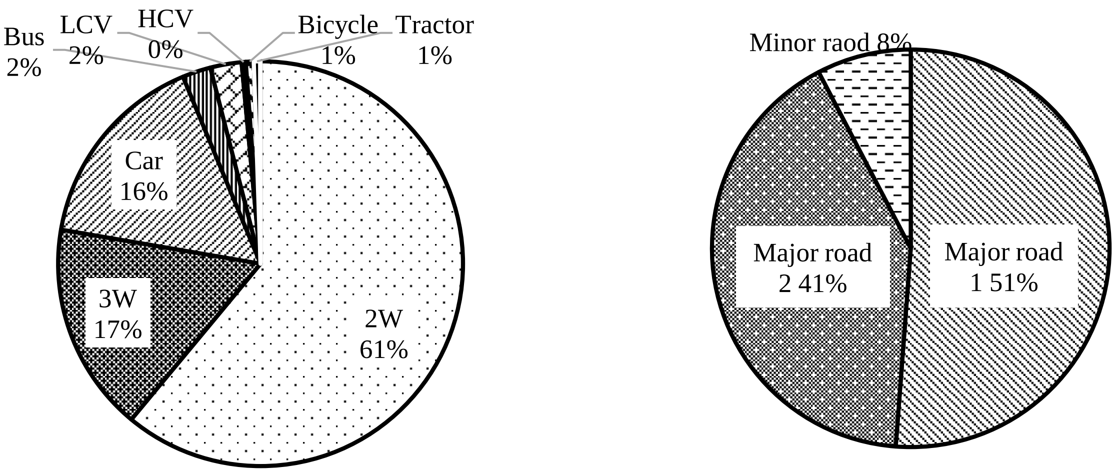
Traffic data collected at the selected intersections were extracted manually using an MPC-HC media player. Vehicles are categorized into two-wheelers (2W), three-wheelers (3W), cars, buses, Heavy Commercial Vehicles (HCV), Buses, Light Commercial Vehicles (LCV), Tractors, and Bicycles. Classified vehicle volume count and turning movements were extracted at each 5-minute interval. The peak hour flows calculated at each intersection are shown in Table 2.

Tab. 2

Peak hour flows

Intersection	Major approach 1		Major approach 2		Minor approach		Peak hour volume (PCU/hr)
	TH	RT	TH	LT	RT	LT	
I	1568	105	1050	171	203	72	3169
II	1094	256	887	101	84	298	2721
III	943	286	1096	118	55	355	2836
IV	1066	285	941	78	93	268	2731
V	1199	191	768	184	139	199	2680

The vehicle composition, the proportion of turning movements, and approach-wise volume count are represented in the form of pie charts as shown in Figure 2.



a) Vehicular distribution

b) Approach-wise distribution

Fig. 2. Percentage of percentage vehicular distribution and leg-wise distribution at the intersection I

From the above pie charts, it is evident that the proportion of two-wheelers is high. A similar trend was observed in all the intersections, varying from 50% to 66%, which comprises half of the total traffic in the intersections. The percentage of cars varies from 15% to 21%, closely followed by the proportion of three-wheelers, which is 10% to 20%. LCVs vary from 2% to 6%. HCVs at the intersections vary from 1% to 7%. It can also be noticed that more than three-quarters of the traffic are private vehicles, which implies that the private mode of transportation is relatively preferred compared to public transportation modes such as buses or three-wheelers. From the approach-wise distribution volume towards Major road-1 and Major road-2 of the intersections cater 45%-52% and 36%-41% and minor roads cater 8%-16% of the traffic. The minor approach which has the least volume among the other approaches is used to estimate the overall performance of the intersection. Hence analysis of minor road movements especially minor right maneuvers is chosen for the present study. It was observed that the pedestrian crossings are significant at the intersections. Hence pedestrian crossings on minor roads and major roads which affect the right-turning movement of minor road vehicles were also extracted. Pedestrian crossing on major road leg-2 and minor roads were recorded at an interval of 5 min to get hourly pedestrian crossings. The hourly pedestrian crossings at each intersection were tabulated in Table 3.

Tab. 3

Hourly pedestrian crossing volume at each intersection

Intersection	Road	Sub Total (ped/hr)	Total (ped/hr)
I	Major	116	208
	Minor	92	
II	Major	112	262
	Minor	150	
III	Major	65	303
	Minor	238	
IV	Major	27	170
	Minor	143	
V	Major	40	83
	Minor	43	

4.1 Occupation time data

Occupation time is defined as the time required to clear a conflict zone by the maneuvering vehicle (the time for which the vehicle occupies the conflict area). Figure 3 illustrates the concept of occupation time (the difference between time stamps at which a vehicle approaches section AA and exits section BB). Occupancy time depends on parameters such as intersection geometry, vehicle type, and driver behavior. The advantage of using occupation time is that it takes into account non-lane behavior, such as vehicles crossing an intersection in a zigzag pattern.

The procedure for extracting occupation time data is identifying the Stop line from the video recorded, the stop line will be determined based on the position where the majority of vehicles stop. The time at which the vehicle arrives at the conflict area (t_a) and departs from the conflict area (t_d) conflict area, as well as the vehicle type is noted. Difference between these two times given Occupation Time as given in Equation 1.

$$O_t = t_b - t_a \tag{1}$$

Where, O_t = Occupation time, t_a = vehicle arrival time at the conflict area, t_b = vehicle departure time from the conflict area.

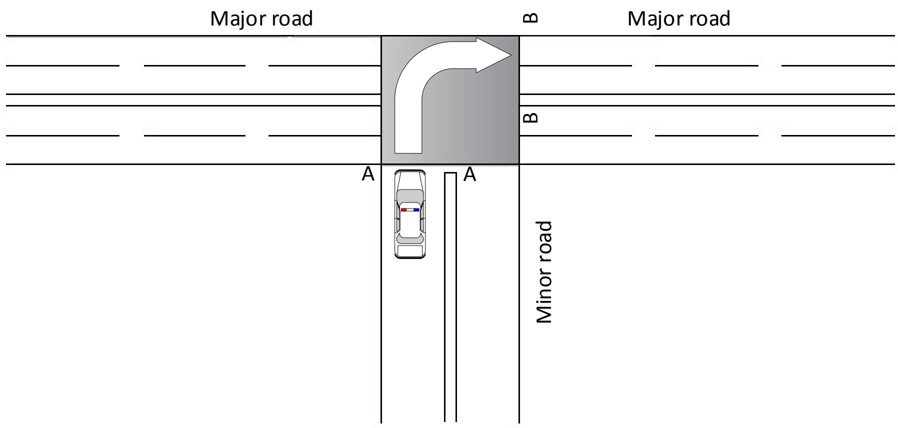


Fig. 3. Occupation time concept

The average occupation time at each intersection is calculated and plotted as shown in Figure 4. Among all the intersections, the average occupation time at the Erragattu intersection is the highest, which is 11.49 seconds, due to reasons such as a larger conflict area and a relatively higher proportion of heavy vehicles as compared to other sites. The average occupation time at an intersection near the Hanamkonda bus stand is the lowest since the conflict area is very small at that intersection, also pedestrian flow and conflicting volume are the lowest at the intersection. Though the conflict area at Madikonda is also large, vehicles maneuver right turns with a larger radius of turn to minimize the travel length in the conflict zone, which resulted in a lower average occupancy time.

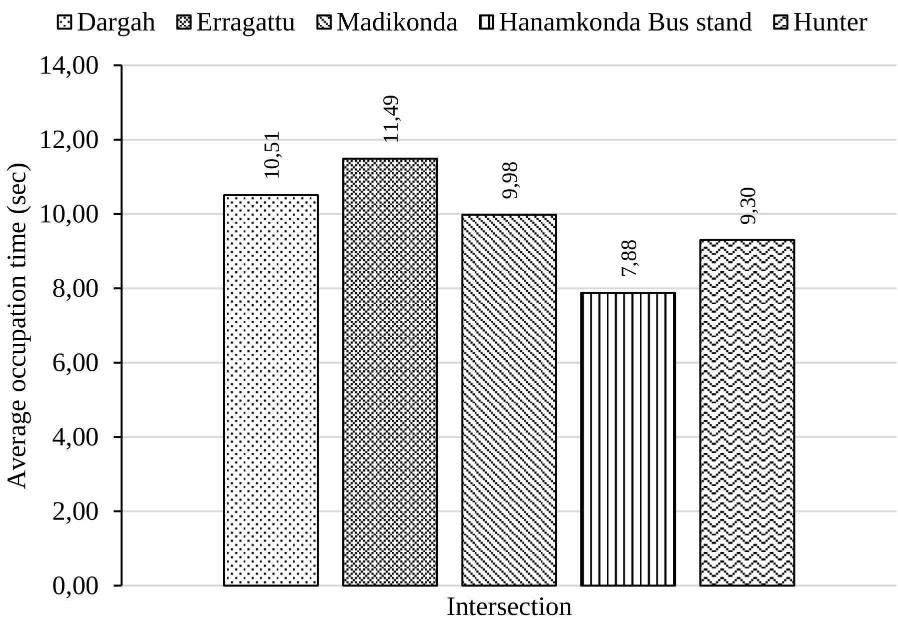


Fig. 4. Average occupation time at each intersection

The average occupation time for each vehicle type at each intersection is shown in Figure 5.

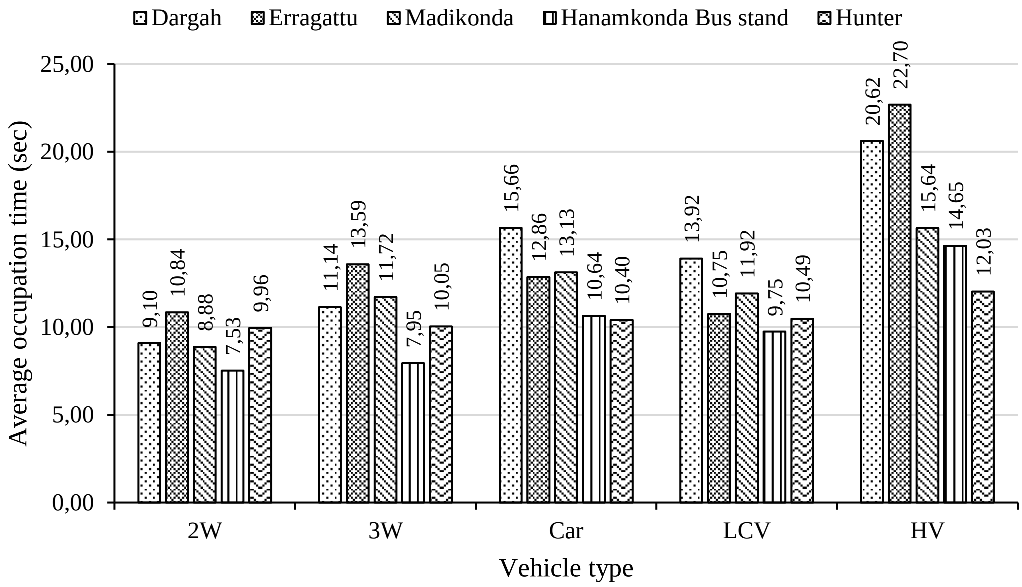


Fig. 5. Average occupation time (sec) for each vehicle type at each intersection

Among all the vehicle types, two-wheelers have the shortest occupation time since the maneuverability of two-wheelers is high and they tend to encroach on the available spaces to clear the conflicting area in a zig-zag pattern. Three-wheelers also have lower occupation time due to ease of maneuvering while turning as well as their aggressive nature when compared to other vehicle types. Cars and LCVs have similar occupation times at all intersections. Heavy vehicles such as buses, tractors, and HCVs have the highest occupation time because of the larger lengths and lower speeds of heavy vehicles. ANOVA test is performed to check whether a significant difference exists between occupation times of five different vehicle groups. ANOVA test result is tabulated in Table 4.

Tab. 4

ANOVA test result

	DF	Sum of squares	Mean squares	F	Pr > F
Between groups	4	2251	562.82	17.11	<0.0001
Within groups	464	15261	32.89		
Total	468	17513			

ANOVA test result indicated that a significant difference exists between the occupation times of different groups. The between-groups variance is significant ($F = 17.11$, $p < 0.0001$), indicating substantial differences between vehicle groups. With a total of 468 degrees of freedom, the test confirms that vehicle type significantly impacts occupation time. The maximum and minimum occupation time of each vehicle category at each intersection is tabulated in Table 5.

Tab. 5

Minimum and maximum occupation time at each intersection (sec)

Vehicle type	Intersection									
	I		II		III		IV		V	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2W	2.88	32.04	3.12	39.26	3.36	32.82	2.31	28.36	2.03	36.25
3W	4.36	31.99	4.47	44.06	5.49	38.50	2.96	26.96	4.87	32.74
Car	4.67	32.79	4.26	38.21	3.84	29.80	3.84	24.14	3.77	29.27
LCV	5.10	37.68	6.10	36.46	6.80	28.78	6.22	25.40	6.17	33.67
HV	7.70	27.51	9.67	35.67	11.75	29.34	12.64	21.48	6.68	31.04

Table 5 presents the minimum and maximum occupation times in seconds for various vehicle types at five intersections. Two-wheelers generally exhibit the shortest times while heavy vehicles have the longest. The data highlights significant variation in occupation times across vehicle types and intersections emphasizing the influence of vehicle size and intersection characteristics.

4.2 Effect of traffic attributes

The effect of different traffic and geometric parameters such as conflicting flow estimated using HCM (2010), the proportion of heavy vehicles, and Pedestrian flow on occupation time were studied, and significant variables are identified from the correlation study.

It is observed from Figure 6 that as the conflicting flow increases, the available gaps in the conflicting flow reduce and that results in more waiting time for vehicles in their minor approach, thereby increasing their occupation time. Heavy vehicles in the conflicting flow have a significant effect on the occupation time. Due to the large vehicle size, the minor approach vehicles hesitate to enter the conflict area, this phenomenon is more predominant in the case of small-sized vehicles. The effect of the pedestrian crossing forces the minor approach vehicles to yield before performing the right turn.

4.2.1 Modeling occupation time

Various parameters that affect occupation time are tested for correlation and significance using correlation analysis. To capture the effect of each parameter on occupation time models are developed for the same dependent variable and traffic parameters as independent variables using regression analysis. Multiple linear regression analysis is performed to achieve the model. Out of data collected 70% of the data is used to develop a model and the data remaining was used to validate the developed model. The relation between the occupation time of right-turning vehicles from a minor road and various traffic and geometric variables considered is modeled and the same is presented in Equation 2.

$$O_t = 1.85 + 0.17P_{HV} + 0.002C_f + 0.01P_f \tag{2}$$

Where, O_t is occupation time in seconds, P_{HV} is percentage of heavy vehicles in conflicting flow, C_f is conflicting flow in pcu/hr, P_f is pedestrian flow in pedestrian flow in pedestrian crossings per hour.

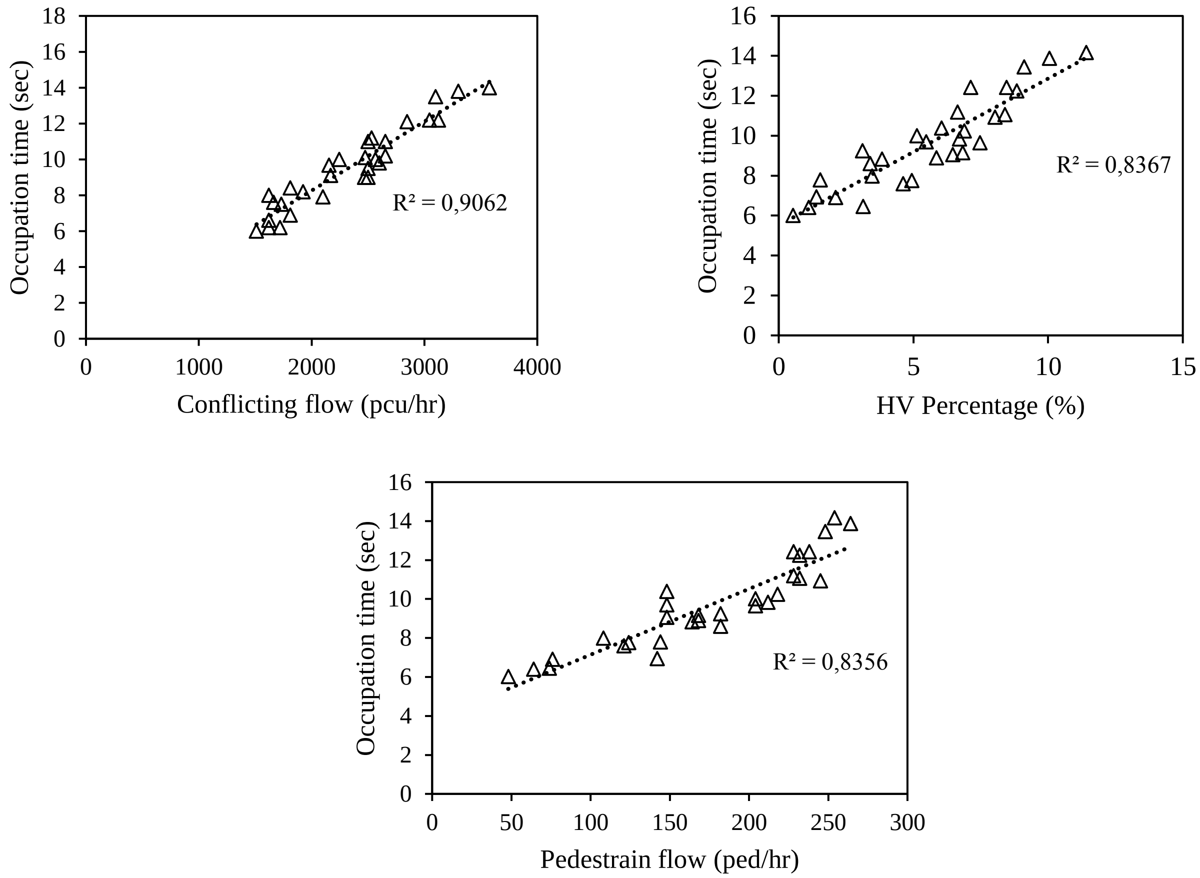


Fig. 6. Plot between occupation time and percentage of heavy vehicles in the conflicting flow

The R^2 value of the model is 0.95 and the standard error for the model is 0.5. The coefficient of P_{HV} shows that as the proportion of heavy vehicles in the conflicting flow increases, the average occupation time also increases. When a vehicle, particularly small-sized vehicle is attempting to enter into the conflict area, it yields whenever the conflicting vehicle is heavy vehicle, looking for a larger gap. This results in increased average occupation time. Similarly, the coefficient of conflicting flow implies that as conflicting flow increases, the average occupation time would also increase due to the vehicle yielding to higher priority movement before entering the conflicting area. As pedestrian flow increases, vehicles of minor roads would yield to let the pedestrians cross, thereby increasing the average occupation time, which illustrates the coefficient of pedestrian flow considering a minimum approach width of a single lane i.e., 3.3m.

4.2.2 Validation of the models

After the development of a model, the validation process is an essential step that determines the extent to which the model corresponds to a real system. The field occupation time was compared with predicted occupation time as shown in Figure 7.

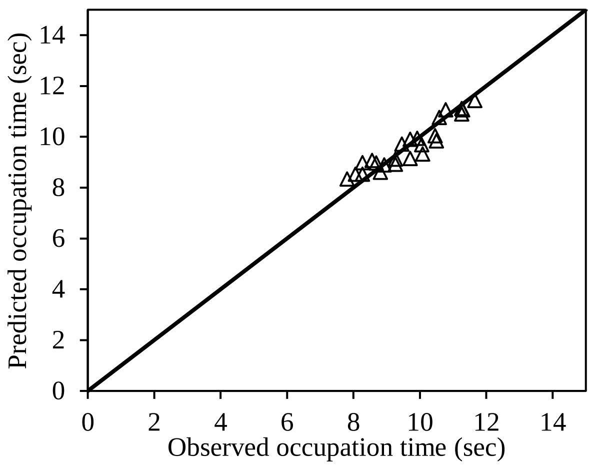


Fig. 7. Validation of average occupation time model for right turning vehicles

The validation for the model developed showed a good prediction of the average occupation time value, i.e., the predicted values of the average occupation time of tight turning vehicles are close to the average occupation time in the field. The model's error and accuracy assessment show a Root Mean Square Error of 1.12, indicating a small average deviation between predicted and observed values.

4.3 Estimation of Gap acceptance data

Gap acceptance is an essential element of microscopic traffic characteristics, which can be used to determine the capacity and delay at an uncontrolled intersection. A minor road driver must decide whether or not a gap is large enough to safely execute the desired maneuver when approaching an intersection with conflicting traffic flows. In general, a driver rejects all gaps smaller than his or her critical gap and accepts the remaining. Thereby, the critical gap is a criterion for determining if a vehicle from a minor road can enter a major road; a critical gap specifies the minimum value of gap that is acceptable to a driver. There are various methods available for the estimation of a critical gap for a movement at an unsignalized intersection. In the present study, the Raffs method was used to estimate critical gaps because of its wide popularity and simplicity of execution.

Reference lines are marked on major and minor approaches. The time at which the subject vehicle, i.e., a vehicle coming from a minor approach crosses the reference line is noted. Then, the time at which the lead/follower vehicles coming from the major approach cross the conflict point is noted. If vehicles from major approaches cross the conflict point before the subject vehicle, then the respective Gap is considered rejected. The Gap in which the subject vehicle crosses the conflict point first is considered accepted. The same procedure is repeated for the entire duration. The data was analyzed and the Number of accepted and rejected gaps are calculated. A graph is plotted with a cumulative number of gaps accepted and rejected on the y-axis and gap size on the x-axis. The Point of intersection of these curves is taken as the critical gap, as shown in Figure 8.

From Figure 8, it can be observed that the critical gap for minor right movement at III-intersection is 4.3 seconds. From the cumulative accepted and rejected curves, it can be noticed that when the gap available was more than 8 seconds, the gap available is mostly accepted. The critical gap was also determined for each vehicle type at each intersection shown in Figure 9.

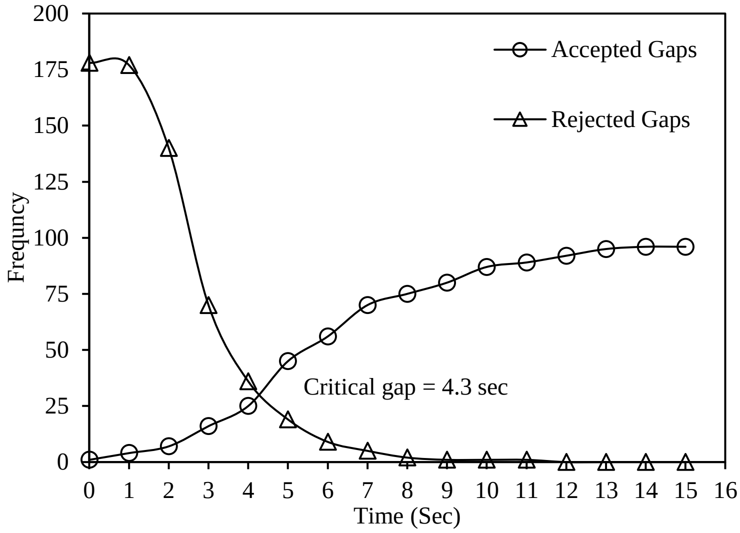


Fig. 8. Plot of cumulative accepted gap and rejected gap vs gap size at III-intersection

From Figure 9, it can be noticed that the critical gap for two-wheelers is the smallest, which is 4.1 seconds. Two-wheelers are small in size compared to other vehicles and due to their size and ease of maneuverability, the critical gap for two-wheelers is the least. The critical gap for three-wheelers is also 3.1 seconds. Due to the aggressive driving nature of the drivers of three-wheelers, they tend to accept smaller gaps and sometimes force their entry to perform the right turning maneuver, hence the smaller critical value. The critical gap value for cars and LCVs is 3.9 seconds and 3.6 seconds respectively, which is slightly large compared to two-wheelers and three-wheelers. The critical gap for heavy vehicles is the highest among all the vehicle types, which is 4.4 seconds, and it can also be noted that they sometimes reject gap sizes as large as 9 seconds. This is due to the difficulty in maneuvering heavy vehicles because of their large size.

Similar results were observed for other intersections. The determined critical gap values and follow-up time are tabulated as shown in Table 6. The follow-up was assumed to be 60 % of the critical gap as established in several studies [26]. Similar trends of the critical gap at III intersection are observed for each vehicle type at all the other intersections. These critical gaps obtained were used in the capacity estimation of the intersections using the Indo HCM Method.

Tab. 6

Critical gap values for each vehicle type at each intersection

Vehicle type	Critical gap (sec) at Intersection					Follow up time (sec) at Intersection				
	I	II	III	IV	V	I	II	III	IV	V
2W	3.1	3.4	4.1	3.4	3.3	1.86	2.04	2.46	2.04	1.98
3W	3.2	4	4.3	3.4	3.8	1.92	2.4	2.58	2.04	2.28
Car	3.9	5.3	5	5	3.9	2.34	3.18	3	3	2.34
LCV	3.6	4	4.8	4.8	4.3	2.16	2.4	2.88	2.88	2.58
Overall	3.3	3.8	4.3	3.5	3.6	1.98	2.28	2.58	2.1	2.16

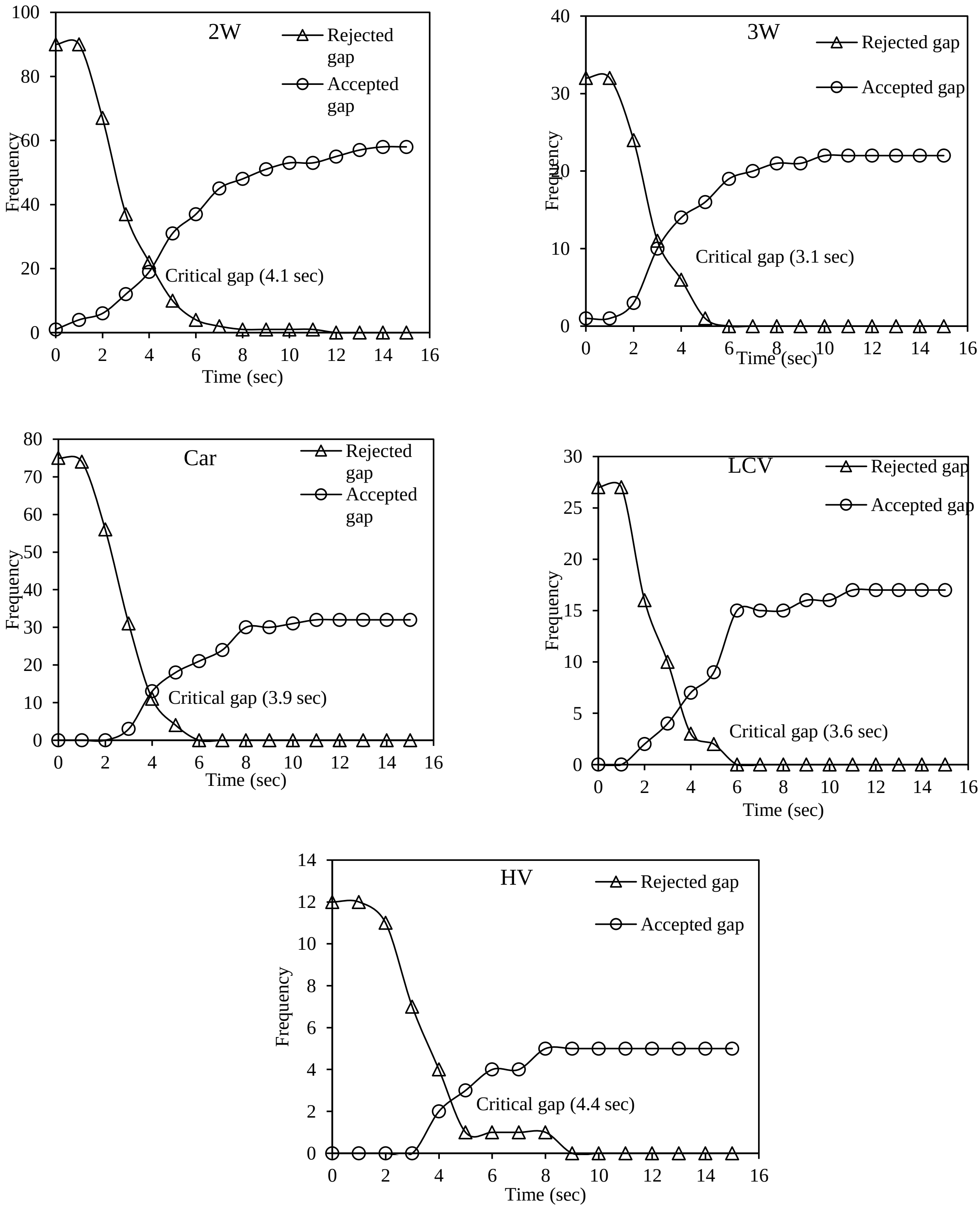


Fig. 9. Plot of critical gap estimation for vehicle types at I-intersection

4.4 Estimation of capacity

The capacity for right turning movement from minor road is estimated at each intersection using Indo – HCM 2017 method. The capacity of a movement is determined using the following Equation 3.

$$C_x = a * V_{c,x} \frac{e^{-V_{c,x}(t_{c,x}-b)/3600}}{1-e^{-V_{c,x}t_{f,x}/3600}} \tag{3}$$

Where C_x = capacity of movement (PCU/hr), $V_{c,x}$ = Conflicting flow for movement (PCU/hr), $t_{c,x}$ = Critical gap (sec), $t_{f,x}$ = follow-up time (sec), a, b = adjustment factors based on intersection geometry.

Conflicting flow is obtained from the traffic count at each intersection. Follow-up time and critical gap values were estimated using the Raff method at each intersection. The capacity estimated at each intersection is shown in the Table 7.

Tab. 7

Capacity

Intersection	Capacity (PCU/hr)
I	1292
II	1224
III	998
IV	1403
V	1563

Capacity for right turning movement is highest at V-intersection due to lower values of critical gap and conflicting flow. Similarly, capacity at IV-intersection is the lowest due to higher critical gap at that intersection as a result of high conflicting flow and pedestrian flow.

4.5 Relation between occupation time and capacity

From the MLR models developed for occupation time, it is evident that occupation time is highly dependent on the conflicting flow and heavy vehicle proportion. Similar to the occupation time, the capacity of the movement also depends on the conflicting traffic volume and the critical gap at the intersection, which in turn depends on the conflicting flow, proportion of heavy vehicles etc. Hence, it can be inferred that the occupation time and capacity at each intersection are related. Therefore, the same is studied at each intersection and the graphs plotted are shown in Figure 10.

It is evident that the capacity of an intersection is highly correlated to occupation time at the intersection. It can be observed that as the occupation time of the movement decreases, the capacity of the same increases and vice versa. When occupation time for a movement is high, vehicles need more time to clear that intersection. That is, fewer ehicles clear the intersection in a given time when occupation time is high, resulting in lower capacity for the movement. It can be concluded that capacity is inversely correlated to occupation time. The relationship between occupation time and capacity is presented in Equation 4.

$$C = -95.7(O_t) + 2202 \tag{4}$$

Where, C = Capacity in pcu/hr, O_t = Occupation time in sec.

The above equation can be used to estimate the capacity of right-turning movement of minor approach at an uncontrolled intersection the using average occupation time of the same movement. Sensitivity analysis was performed to provide robustness of the model and the magnitude of changes in capacity when occupancy time shifts due to variations in conflicting traffic flow, heavy vehicle proportion and pedestrian influence. The constant (-95.7) is considered as the rate of change or sensitivity coefficient of capacity with respect to occupancy time. The sensitivity analysis was performed using a baseline occupancy time and capacity of 10 sec and, 1245 pcu/hr. A 10% decrease in occupancy time increases capacity to 1340.70 pcu/hr. The sensitivity analysis shows that capacity is highly sensitive to changes in occupancy time. A small variation in occupancy time, whether due to increased conflicting traffic flow, higher heavy vehicle proportions, or pedestrian volume, leads to significant changes in intersection capacity. The model was validated using field data as shown in Figure 11.

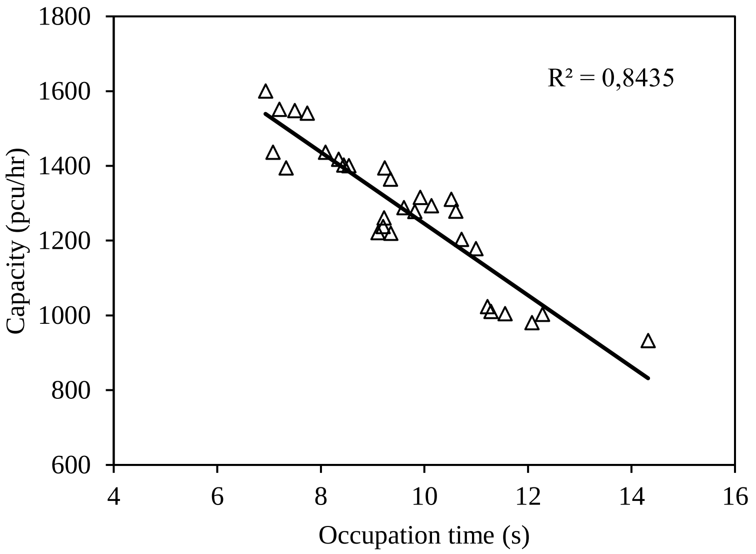


Fig. 10. Relation between occupation time and capacity

The average occupation time of the movement obtained from Equation 2 can be substituted in Equation 4. This would serve as a simpler approach to estimating capacity.

5. CONCLUSIONS

Following are the conclusions obtained from the results of the present study:

- Two-wheelers have the lowest occupation time among vehicle categories because their maneuverability is high and they tend to squeeze into available spaces to clear the conflict area. Three wheelers also have lower occupation time due to ease of maneuver while turning as well as their aggressive nature when compared to other vehicle types

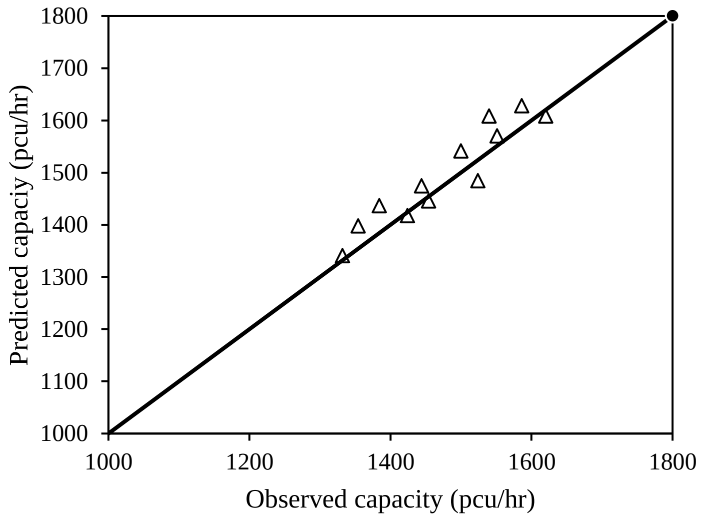


Fig. 11. Validation of estimation of capacity for right turning traffic

- Cars and LCVs have similar occupation time at all the intersections. Heavy vehicles such as buses, tractors and HCVs have the highest occupation time because of their larger length and lower speed of heavy vehicles.
- From the correlation analysis, it was observed that the occupation time has a positive correlation with the percentage of heavy vehicles in the conflicting flow, conflicting flow, pedestrian flow and approach width and has a negative correlation with the presence of median on minor road
- There is an increase in occupation time with an increase in conflicting flow. It is because as the conflicting flow increases, the available gaps in the conflicting flow decrease, resulting in increased waiting time for minor road vehicles to to safely execute the desired maneuver, hence increasing their occupancy time. It was observed that for every 5% increase, occupation time increased by 0.2 sec
- There is an increase in occupation time with increase in % of heavy vehicles in the conflicting flow. It is because when the size of vehicles is large, drivers on the minor road are hesitant to enter the conflict area to perform the desired movement and wait for a longer time resulting in longer occupation time. It was observed that for every 1% increase, occupation time increased by 0.35 sec.
- There is an increase in occupation time with an increase in approach width. It is because as the approach width increases, the area of conflict increases and also the turning radius decreases resulting in higher occupation time. It was observed that for every 0.5m increase, the occupation time increased by 0.25 sec.
- There is an increase in occupation time with an increase in pedestrian flow. It is because as the pedestrian crossings increase, it forces the minor road vehicles to yield before performing the right turn there by increasing occupation time. It was observed that for every 5% increase, the occupation time increased by 0.13 sec.
- At every intersection, two-wheelers have the lowest critical gap value, closely followed by three-wheelers. Two-wheelers being smaller in size and easy to maneuver accept smaller gaps but in the case of three-wheelers, they force their entry due to their aggressive driving behavior and hence the lower critical gap.

- The critical gap for heavy vehicles is the highest among all the vehicle types. This is due to the difficulty in maneuvering heavy vehicles because of their large size.
- Capacity is found to be negatively correlated with occupation time. It is because when the occupation time of a movement is high, vehicles require more time to clear the intersection, which implies that fewer vehicles clear the intersection in a given amount of time, hence reducing the movement's capacity.

The findings highlight the significant impact of these factors on occupation time and, consequently, on intersection capacity. The results, particularly the linear regression model developed, contribute to a better understanding of how mixed traffic interacts at uncontrolled intersections, offering a more accurate method for capacity estimation in such environments. The results of this study align with existing literature by confirming the impact of conflicting flow, heavy vehicle proportion, and pedestrian flow on intersection capacity. However, the study's use of occupation time provides a more accurate capacity estimation in mixed traffic conditions, addressing the limitations of traditional gap acceptance models typically used in homogeneous traffic studies. This approach offers a significant improvement in predicting real-world intersection performance under complex traffic scenarios.

Despite the valuable insights gained, this study has several limitations:

- The study was conducted at only five intersections within Warangal city. The results may not be generalizable to intersections with different traffic compositions or in other cities with different driving behaviors and road geometries.
- The extraction of traffic data from video recordings was performed manually. This process could introduce biases or inaccuracies in the measurement of occupation time and vehicle counts.
- The study did not account for all possible variables that could influence intersection capacity, such as weather conditions, driver aggression levels, or variations in traffic patterns on different days of the week.

Scope for future research are:

- Expanding the Geographic Scope: Conducting similar studies in various cities across different regions, including rural and urban areas with varying traffic conditions, could help in developing a more universally applicable model.
- Implementing automated data extraction techniques, such as machine learning algorithms or computer vision tools, could enhance the accuracy and efficiency of data processing and reduce potential biases.
- Future studies could consider a broader range of variables, including environmental factors, driver psychology, and real-time traffic management interventions, to refine the capacity estimation models further.

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