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Roadway and Traffic Attributes Influencing Occupancy Time of Minor-Road Right-Turning Vehicles at Urban Uncontrolled Intersections

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Abstract
The performance of uncontrolled intersection is usually measured based on delay of the least priority movement. Perhaps, most of the studies assumed single stage crossing and had to overlook additional factors for estimating occupancy time. The present study examines occupancy time under two-stage crossing under the influence of roadway and traffic attributes. Field data for this study are collected at five different isolated intersections. The analysis of field data is performed by observing the movements of individual vehicles from the minor road approach by considering various factors affecting it under mixed traffic conditions. And it was observed that Two-wheelers are tended to encroach into smaller gaps in between the vehicles due to its physical dimension and easy maneuvering followed by threewheelers. The occupancy time is observed had strong correlation with conflicting area, conflicting flow the proportion of U-turning major road traffic, vehicle dimension, and the increase of median width.

Author Keywords**.** Occupancy Time, Two-Stage Crossing, Uncontrolled Intersection, Roadway, and Traffic Attributes

Type: Research Article

1. Introduction

India is experiencing rapid urbanization with astounding growth in vehicular traffic is affecting the efficiency of that challenging the planning and design of current transportation infrastructure requirements. Road Intersections acts as nodes for the road infrastructure. These nodes are controlled or uncontrolled intersections. Generally, Performance of unsignalized/uncontrolled intersections is measured based on delay encountered by the least priority movement the right turning traffic from minor roads. As maneuvering through intersection with low priority is complex as turning movements work on the principle of the relative priority of traffic movements where vehicles can cover any available space on the roadway. Mostly uncontrolled intersections are designed under lighter conflicting traffic condition. The increasing volume of conflicting traffic leads to more delays for the least priority movement such as right turns from minor road approach.

Delay is the extra time experienced by driver or vehicle under prevailing conditions than free-flow conditions of traffic. Highway Capacity Manual (HCM 2010) and Indian Highway Capacity Manual (Indo-HCM 2017) uses the gap acceptance method to estimate control delay at two-way stop-controlled intersections. This approach has several drawbacks as it cannot be applied to the traffic stream which lacks priority rules and the presence of pedestrians. The additive conflict stream method was developed to overcome these shortcomings in which occupancy time was used to estimate the capacity of movements in the conflicting group. Occupancy time has a key role in measuring the performance of uncontrolled intersections. Occupancy time is defined as the maneuvering time of the subject vehicle to traverse through the conflicting area. The flow which creates conflicts with the subject vehicle is considered as conflicting flow. Occupancy time is measured based on the assumption that the subject vehicle travels without being blocked. The present study considers two-stage crossing which includes median delay and additional time consumed by the subject vehicle at the median due to blockage. The main objectives of the present study are to estimate the occupancy time under single stage and two-stage crossing and examine the effect of roadway and traffic factors such as percentage of U-turn major traffic, conflicting traffic, area of conflict, median width on right turning maneuvers from minor road approach.

2. Literature Review

The investigation studies on delay at uncontrolled intersections have been carried out by assuming the law of priority at uncontrolled intersections under both homogeneous and heterogeneous traffic conditions based on the capacity. Most of the works of literature estimated capacity using gap acceptance theory and regression equation. There are limited studies focused on the occupancy time of vehicles which is a key parameter in estimating capacity. Performance and safety assessment of uncontrolled intersections is regulated by delay (Satish, Abhishek and Ashalatha 2009). HCM 2010 and Indo-HCM 2017 used the equations under limited priority to forecast capacity and a maximum delay of least priority movement. The critical gap method of (HCM 2010) to polish conditions affecting capacity and delay models by (Choudur 2005).A delay model for the stopped controlled intersection was developed based on the probability of gap acceptance behavior using conflicting flow by (Samer and Michael 1994). Delay equations at oversaturated conditions based on reserve capacity like the time-dependent queue model by (Brilon 1995). Empirical models were developed by (Al-Omari and Benekohal 1999) to estimate service delay as a function of conflicting flow.

The additive Conflicting Technique was found to be suitable to understand the behavior of flow at uncontrolled intersection. A simplified method to estimate the capacity of signalized intersections using the addition of critical traffic movements (Glueue 1972). further Additive Conflict flow (ACF) was redesigned for All-Way Stop Controlled (AWSC) intersection with a single-lane approach (Wu 2000). The capacity of Two-Way Stop Controlled intersections using conflicting flow by developed by (Brilon and Wu 2001). As ACF studies the probability of conflicting points being occupied a model was developed for delay at stop-controlled intersections based on the probability of accepting a gap based using ACF (Madanat, Cassidy and Wang 1994). Conflict technique was used to develop capacity models for three types of unsignalized intersections by (Li and Tian 2009). Estimated critical gap using intersection occupancy time which is taken as the meeting point of the distribution function of accepted gaps and lags with the frequency distribution curve of occupancy time by (Chandra, Mohan and Gates 2014). Capacity obtained from the conflict method at intersections with flared and without flared intersections was compared and found occupancy time is inversely proportional to the capacity of the approach (Prasetijo, et al. 2014). Occupancy time of uncontrolled and semi-controlled intersections were compared based on additive conflicting techniques by (Asaithambi and Anuroop 2016). Delay and driver influencing turning time were evaluated at uncontrolled intersections using conflicting flow as an influencing variable by (Datta, Rokade and Rajput 2020).

Most of the studies on performance evaluation is available under homogeneous traffic where priority rules are followed strictly such as at TWSC. India has mixed traffic conditions and multiple numbers of factors are usually present on the urban roads. It makes study methodology considerably different from those suggested under homogeneous traffic conditions. The non-lane discipline with a lack of knowledge of priority rules and regulations prevailing in a heterogeneous traffic can alter the maneuvering capability of vehicles at uncontrolled intersections. Thus, it is necessary to study the occupancy time characteristics of least priority movements for all types of vehicles to evaluate operational performance of uncontrolled intersections under mixed traffic conditions.

3. Objectives and Scope of study

The present study investigates the characteristics of occupancy time under varying roadway and traffic attributes for the low priority movement at uncontrolled T-intersections under heterogeneous traffic conditions. The scope of the present study is limited to T-intersection with a divided four-lane major roads and two-lane minor roads.

4. Methodology

Study methodology has been adopted for analyzing the occupancy time of minor approach right-turning traffic at uncontrolled T-intersections. Sites for carrying out field study are selected based on a reconnaissance survey by visiting location and its characteristics. The field surveys have been conducted at selected intersections to collect necessary data for the study. The traffic volume for different turning movements is recorded for setting the priority movements at intersection. The schematic diagram of intersection showing traffic movements is provided in **Figure 1**.

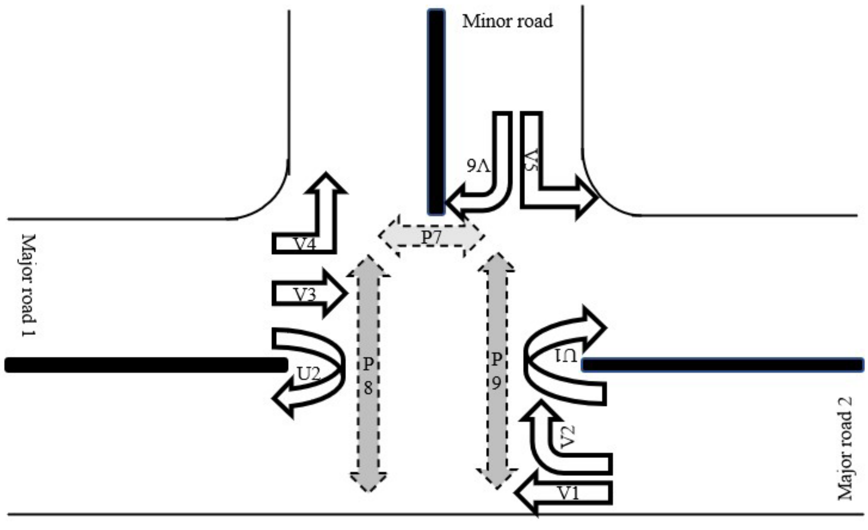


Figure 1: Vehicular and pedestrian traffic movements at uncontrolled intersection

The design and analysis guidelines suggested that the highest priority movement will have the least occupancy time and the least priority movement will have the highest occupancy time (HCM 2010, Indo HCM 2017). Various flow movements considered according to their priorities are shown in **Table 1**.

Priority of movement	Maneuvering movements
First Priority	V_1, V_3, V_4, V_5, & P_7
Second Priority	U_1, U_2, V_2, P_8, & P_9
Third priority	V_6

Table 1: Priority of movements at uncontrolled T-intersection

Each movement at an uncontrolled intersection faces a different set of conflicts that are directly related to the nature of the movement. The following equations (1) to (4) are used to determine the conflicting flows.

$$\mathrm{Vc},6 = \mathrm{V1} + \mathrm{V3} + 2 * (\mathrm{V2} + \mathrm{U2}) + 0.5 * \mathrm{V4} + \mathrm{P7} + \mathrm{P8} \quad (1)$$

$$Vc,3 = V2 + V6 + 0.5 * (U2 + U1) + P8 + P9 \quad (2)$$

$$Vc,2 = 2 * V6 + V3 + 0.5 * U1 + P9 + P7 \quad (3)$$

$$Vc,1 = 0.5 * (V6 + V2 + U1 + U2) + P9 + P8 \quad (4)$$

The travel time data were extracted manually. Field data analysis is performed for single-stage and two-stage crossing by using extracted travel time data from videos. Statistical parameters are analyzed, and mathematical relation established for determining occupancy time.

5. Study Location and Data Collection

The traffic flow data was collected at five uncontrolled three-legged type intersections in Warangal city, India. The intersections are selected in such a way that the major and minor approaches should be nearly perpendicular to each other and free from the effect of any other intersections in same locality. The arial view of selected intersections is shown in **Figure 2**(a) to **Figure 2**(e).

(a) Nehurnagar (17°42'50.1"N 83°18'12.7"E)

(b) Vidyanagar (18°01'04.7"N 79°32'48.6"E)

(c) Ramanthnagar (17°58'20.4"N 79°30'12.5"E)

(d) Dharga junction (17°59'22.5"N 79°31'58.1"E)

(e) Kakathiya govt college (18°00'20.3"N 79°34'01.4"E)

Figure 2: Google images of the intersections identified

The selected intersections join major road and minor road approaches with no signs of any priority. Intersections has no influence of stop and go maneuvering of public transport and are free from influence of signalized intersection on upstream/downstream side. The videographic method was used to collect the traffic data. The video camera was placed at a vantage point to have an unobstructed view of the intersection covering both major and minor road traffic. The traffic data were collected for eight hours to study both free-flow traffic and peak hour traffic. The traffic data were collected on weekday traffic that is from Monday to Friday.

6. Field Data Analysis

The traffic video recordings were played by Avidemux software which runs at one frame per second basis to have minimum errors. The traffic data was extracted atone-minute time interval in which the entry time and exit time of each vehicle was recorded. Two-wheeler (2W), Three-wheeler (3W), Car, Light Commercial Vehicle (LCV), and Heavy Commercial Vehicle (HCV, which includes buses and trucks). The intersection details such as approach width, median width, and conflicting area are given in **Table 2**.

Intersection name		Nehrunagar	Vidyanagar	Ramanthnagar	Dharga junction	Kakathiya govt college
Approach width (m)	Major	5.4	5.29	7.79	8.38	5.77
	Minor	4.8	4.45	6.93	6.17	5.5
Median width (m)	Major	1	1.5	2	1.8	5.5
	Minor	0.5	0.5	2	1.8	0.5
Conflict area (m^2)		208	305	261	348	116

Table 2: Geometric features of uncontrolled T-intersections

In evaluate travel time through uncontrolled intersections. The reference line evaluation is the most important estimation of occupancy time, reference lines are drawn at each approach. The reference lines on major approaches are drawn near the median opening and for the minor approach the reference line was evaluated based on vehicle stopping at the intersection before entering the conflict area. The areas within the reference lines are considered as conflicting areas as shown in **Figure 3**.

Figure 3: Schematic diagram of uncontrolled T-intersection

6.1. Vehicular and Pedestrian Volume Data

The vehicular volume on minor roads with right-turning traffic at busy and under free-flow conditions was recorded at early hours. The observed traffic volume was converted into Passenger Car Units (PCU) as recommended by (Indo-HCM 2017). The traffic volume observed at intersections is shown in **Table 3**. The traffic composition extracted from the observed volume of the major and minor roads is illustrated in **Table 4**.

Traffic volume (PCU)						
Approach	Movement	Intersection				
		(a)	(b)	(c)	(d)	(e)
Minor	Right turn	866	534	627	428	310
	Left turn	228	178	108	89	74
Major 1	Through	1164	811	1159	954	570
	Left turn	297	189	139	247	30
	U-turn	158	310	69	58	43
Major 2	Through	1269	1087	863	1107	491
	Right turn	831	137	223	152	145
	U-turn	56	203	25	42	29

Table 3: Turning volume of traffic flow at uncontrolled intersections

Intersection	**Percentage of vehicular traffic (%)**									
	Minor road					Major road				
	2W	3W	Car	LCV	HCV	2W	3W	Car	LCV	HCV
(a)	46	41	8	3	2	57	32	9	1	1
(b)	67	14	13	4	2	66	14	13	4	3
(c)	72	12	11	4	1	68	17	12	5	3
(d)	75	16	6	2	1	61	20	14	4	1
(e)	65	23	10	1	1	64	23	10	2	1

Table 4: Vehicular composition data at an uncontrolled intersection

The vehicle types 2W, 3W, and Cars cover 90 to 95 percent of the traffic composition, and heavy vehicles such as trucks and buses are found in less than 5 percent of the traffic stream. **Table 5** shows the pedestrian volume during the busy hours.

Crossing pedestrian volume (Ped/hr)					
Approach	Intersectio			n	
	(a)	(b)	(c)	(d)	(e)
Minor	128	204	45	254	85
Major 1	31	59	17	97	40
Major 2	28	35	26	23	35

Table 5: Pedestrian volume at uncontrolled intersections

6.2. Estimation of Conflicting Traffic Flow

Conflicting flow was estimated using (Indo-HCM 2017) method with an additional U-turning factor and the weightings given to the turning movements are based on the crossing, merging, and diverging movement of the traffic. Conflicting flows were measured for each movement which is shown in **Table 6**.

	Conflicting flow (conflicts/hour)					
Approach	Movement	Intersection				
		(a)	(b)	(c)	(d)	(e)
Minor	Right turn	4719	3150	2738	2956	1491
Major 1	Through	1863	1022	940	750	530
Major 2	Through	1015	686	515	460	302
	Right turn	3080	2220	2497	2108	1310

Table 6: Conflicting flow estimated for movements

7. Analysis of Occupancy Time

The computation of occupancy time needs a reference line at each approach of the intersection where the vehicle tends to stop. The occupancy time of vehicles has been analyzed for the movement having the least priority such as right turns from minor roads. Occupancy time is the time difference between vehicles maneuvering through the conflicting area as shown in **Figure 4**.

Figure 4: Reference line for right-turning minor traffic

Entry time of conflicting area at reference line *a* is t_1, time of entry at the reference line *b* is t_2. Intermediate stopping time is the waiting time at the median when the gap to merge with the major stream 2 is less and the time of exiting the conflicting area at reference line *c* is noted as t_3 and occupancy time O_t of the right turning vehicle maneuvering the conflicting area from minor streams and it can be determined from the Equation 5.

$$Occupation\ time\ Ot = (M1) + (Wm) + (M2) \tag{5}$$

Where M_1 is Maneuvering time (t_1-t_2), W_m is Waiting time at median and M_2 is Maneuvering time (t_2-t_4)

The calculation of occupancy time was estimated based on the reference lines. The analysis was performed individually for five vehicular types for all turning movements as shown in **Table 7**.

Intersection	Approach	Movement	Occupancy time (sec)				
			2w	3w	Car	LCV	HCV
(a)	Minor	Right	11.55	12.48	14.98	13.74	14.32
	Major1	Through	6.45	7.98	7.04	7.92	7.24
	Major2	Right	10.19	12.23	10.52	12.23	13.56
		Through	4.91	7.38	7.65	7.35	7.9
(b)	Minor	Right	13.49	15.53	20.31	19.33	24.7
	Major1	Through	4.27	4.6	5.59	4.1	12.97
	Major2	Right	7.14	7.57	10.04	11.54	12.01
		Through	6.43	5.8	11.93	3.6	3.33
(c)	Minor	Right	7.54	8.27	10.25	9.58	12.39
	Major1	Through	3.86	4.87	5.91	5.64	6.29
	Major2	Right	5.84	8.54	13.89	12.51	15.12
		Through	3.48	4.59	5.48	4.8	5.84
(d)	Minor	Right	8.36	10.23	11.56	12.89	15.21
	Major1	Through	3.92	4.21	4.62	4.58	5.23
	Major2	Right	6.11	8.36	12.24	12.56	15.69
		Through	3.52	3.86	3.65	3.32	4.2
(e)	Minor	Right	4.79	5.68	5.75	6.62	9.51
	Major1	Through	3.68	3.9	4.23	5.3	5.9
	Major2	Right	4.29	4.89	5.25	5.67	7.2
		Through	3.42	3.5	4.01	4.21	4.78

Table 7: Occupancy time of each vehicle type for all crossing movement

It was observed minor right-turning traffic had the least priority and had a large occupancy time to clear the conflicting area followed by right-turning from major approaches and through traffic. Further, observation of single stage and two-stage crossing of minor approach right-turning traffic are studied separately. Average occupancy time of right tuning minor approach movements under single stage (no median waiting time) are shown in **Table 8** and **Table 9**.

Intersection	Approach movement	Occupancy time (Ot)				
		2w	3w	Car	LCV	HCV
(a)	Minor right turning movement	7.58	8.19	9.83	9.02	9.40
(b)		8.85	10.19	13.33	12.69	16.21
(c)		4.95	5.70	7.45	7.09	9.06
(d)		5.49	6.32	8.26	7.86	10.05
(e)		3.14	3.39	4.07	3.74	3.89

Table 8: Average occupancy time of minor right-turning vehicle under single-stage crossing

No.	Approach movement	Occupancy time (sec)														
		2w			3w			Car			LCV			HCV		
		M_1	W_m	M_2	M_1	W_m	M_2	M_1	W_m	M_2	M_1	W_m	M_2	M_1	W_m	M_2
(a)	Minor right turning movement	4.37	3.97	3.22	4.72	4.28	3.48	5.66	5.14	4.18	5.19	4.72	3.83	5.41	4.92	3.99
(b)		5.10	4.63	3.76	5.87	5.33	4.33	7.68	6.97	5.66	7.31	6.64	5.39	9.34	8.48	6.88
(c)		2.85	2.59	2.10	3.13	2.84	2.30	3.87	3.52	2.86	3.62	3.29	2.67	4.68	4.25	3.45
(d)		3.16	2.87	2.33	3.87	3.51	2.85	4.37	3.97	3.22	4.87	4.43	3.59	5.75	5.22	4.24
(e)		1.81	1.64	1.34	2.15	1.95	1.58	2.17	1.97	1.60	2.50	2.27	1.85	3.59	3.26	2.65

Table 9: Average occupancy time of minor right-turning vehicle under two-stage crossing

In two-stage crossing, the right turning traffic tends to decelerate or even halt at the median due to insufficient gap to merge in major road 2 shown in **Figure 4**. The intermediate median waiting time is observed higher for car, HCV, and LCV as they require a large radius of turn and larger gaps required to merge. To understand the additional time in crossing the conflicting area for minor right-turning vehicles compared to occupancy time under low traffic are shown in **Table 10**.

Intersection	Approach Movement	Occupancy time (sec)				
		2w	3w	Car	LCV	HCV
(a)	Minor right turning movement	2.4	3.9	5.84	5	7.04
(b)		2.94	4.22	5.91	5.89	7.12
(c)		2.8	4.14	5.88	5.36	7.44
(d)		3.36	4.36	5.95	6.01	7.18
(e)		2.38	3.52	5.21	4.41	6.62

Table 10: Average occupancy time of minor right-turning vehicles observed under low traffic

The occupancy time has been analyzed for five subject vehicles of minor approach right traffic and are observed quite higher when compared with free-flow traffic. This is due to the large gaps available in the conflicting traffic and no median waiting time.

As 90 percent of the traffic flow consists of 2w and 3W. A hypothesis test was conducted to check the dependency of occupancy time on 2W and 3W. ANOVA test was conducted to check the means of vehicle types are significantly different from each other. The statistics of the ANOVA test are shown in **Table 11** with the stated null hypothesis as mean occupancy times of 2W, 3W are equal.

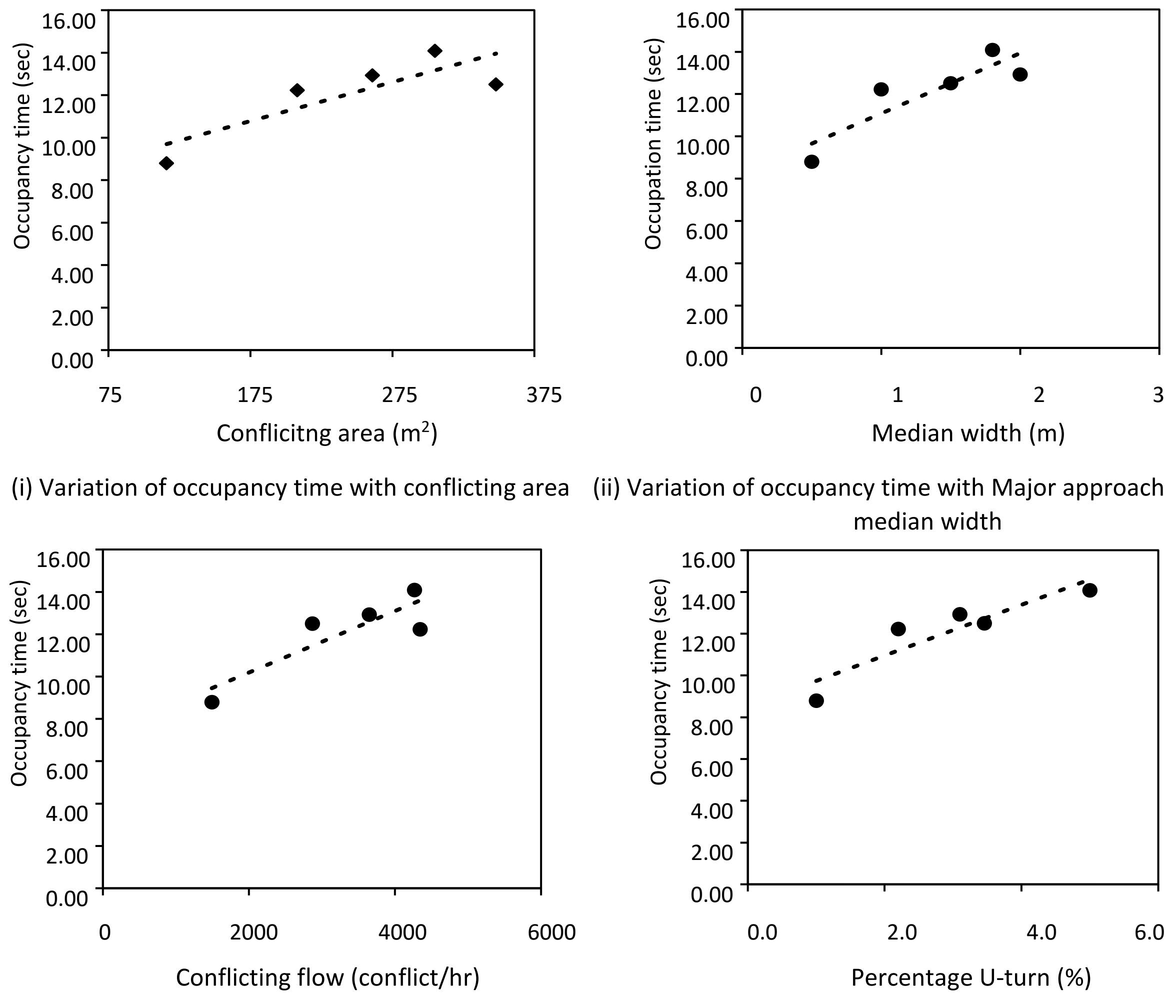
Movement	Vehicle types	T Statistics		P-Value	Remarks
		Computed	Critical		
Minor right turning	2W, 3W	3.24	1.96	0.001	At ∞ = 0.05, null hypothesis is rejected

Table 11: Statistics of ANOVA test for minor right-turning traffic

However, the null hypothesis is rejected as calculated T is greater than the critical value which shows that the mean occupancy times of different types of vehicles are statistically different.

7.1. Effect of Roadway and Traffic Characteristics

The occupancy time of the right-turning minor stream was analyzed for five different vehicle types at all the intersections. The variation of occupancy time due to the size of the conflicting area, the width of the median on a major road, conflicting traffic and percentage U-turning traffic are studied. Plots were made between occupancy time and the factors that seem to be affecting occupancy time shown in (**Figure 5**).



(i) Variation of occupancy time with conflicting area (ii) Variation of occupancy time with Major approach median width

(iii) Variation of occupancy time with the conflicting flow (iv) Variation of occupancy time with a

Figure 5: Relation between average occupancy time with varying roadway and traffic attributes

A linear positive correlation was observed between the factors considered and average occupancy time. The mathematical equations fitted for occupation time for the factors found significantly influencing such as conflicting area, median width on major approach, conflicting flow, and percentage of U-turn are shown in **Table 12**.

Type of movement	Influencing factor		Occupancy time equation	Correlation coefficient R^2
Right turning movement from the minor stream	Roadway	Area of conflicting (A_c)	$O_t = 0.0184(A_c) + 7.56$	0.7
		Median width (M_w)	$O_t = 2.85(M_w) + 8.23$	0.77
	Traffic	Conflict flow (C_f)	$O_t = 0.0015(C_f) + 7.28$	0.75
		U-Turning traffic (U_t)	$O_t = 1.21(U_t) + 8.52$	0.83

Table 12: Mathematical equation fitted for average occupancy time for varying roadway and traffic characteristics at each intersection

The earlier studies on occupancy time models for right turning movement exponential trend was observed under heterogeneous traffic conditions. A significant increase in occupancy time is observed with an increase in conflicting traffic flow as the available gaps for the minor stream are very less. Higher occupancy time was obtained at low conflicting traffic because of the additional factors influencing occupancy time. Multiple linear regression models were developed for roadway and traffic characteristics. Occupancy time model for varying conflicting area, median width, conflicting flow, and percentage u-turning traffic was shown in **Table 12**.

Type of movement	Roadway and Traffic characteristics	Occupancy time equation	Correlation coefficient R^2
Right turning movement from the minor stream	Area of conflicting (A_c), Median width, Area of conflicting (A_c), and Median width (M_w)	$O_t = 6.39 + 0.01 \times (C_f) + 0.71(M_w) + 0.01(C_a) + 0.32(U_t)$	0.9

Table 13: Aggregate Mathematical models developed for average occupancy time for roadway and traffic characteristics

8. Conclusions

The present study's objective is to analyze the occupancy time of right-turning traffic at uncontrolled urban intersections and to develop mathematical relations relating occupancy time to the roadway and traffic factors influencing occupancy time. For this study traffic data were collected at five urban uncontrolled T-intersections in two cities using the video graphic method. Occupancy time estimation had a high impact due to variable geometric, traffic, and lack of lane discipline and priority rules. Occupancy time models were developed for the factors found to be influencing occupancy time. On average 2W and 3W have lesser occupancy time compared to all other vehicles due to their dimensions and flexible lateral movement. Heavy vehicles have a larger occupancy time because heavy vehicles need more space to enter the intersection, require larger gaps and require a larger turning radius. ANOVA test shows that the mean occupancy time of each vehicle type is significantly different, and it depends on the type of vehicle class. Single-stage and Two-stage crossing of minor approach right turning traffic was studied and 4 to 5 sec for higher occupancy time was observed in two-stage crossing. A positive correlation was observed between the variables and mean occupancy time. The model estimated that with an increase in the area of conflict the occupancy time increases substantially. Median width allows the right-turning vehicles and U-turning vehicles to halt and accept the required gap before entering the second major traffic. U-turning traffic are quite significant in estimating conflicting flow and also interrupts the minor right turning merging traffic movement. The model developed in the study can be used to estimate the movement capacity using additive conflict stream method at uncontrolled intersections under mixed traffic conditions with varying roadway geometry.

8.1. Limitation of the Present Study

I. No skewed intersection was considered in examining occupancy time.
II. Reference line is taken as static based on observation.
III. Distinct geographical locations and data sets are necessary to obtain further insights on occupancy time for varied geometric and traffic conditions.

8.2. Future Scope

Exclusive analysis of occupancy time under the influence of side frictions like on-street parking, bus stop, encroachments, etc., can be a direction for future research. Moreover, acceleration and deceleration profiles of individual vehicles at higher traffic flows on developing composite models for representing occupancy time better. This may assist in more accurate traffic planning at urban uncontrolled T-intersections.

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