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Effect Of U Turns On Capacity Reduction At Signalized Intersection

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Abstract—Right turn movements have been considered as one of the major resources of traffic operations and safety problems in the roadway system. Approaches used to achieve control of right turns includes separation of the right turns in exclusive right turning lanes, use of U turns either at or after the intersection and consolidation of median opening. The concept of U turns as an alternative to direct right turn movements is a relatively new approach and has recently been implemented in several locations. The safety gain from such a design is due to decrease in the number of conflicting points at the intersection. This study analysed the effect of U turning vehicles on the right turn saturation flow rate. Data regarding queue discharge time and U turning vehicles were taken at three signalized intersections in Trivandrum city, Kerala, India. Based on the data collected, a second degree polynomial regression model was developed which estimated the relationship between average queue discharge time for each turning vehicle and varying percentage of U turning vehicles. Adjustment factors for varying percentages of U turning vehicles were also developed by using the regression model. The adjustment factor developed in this study was used in estimating the capacity reduction due to varying percentage of U turning vehicles at signalized intersection.

***Keywords**— Adjustment factor, Queue discharge time, Regression model, Right turn, U turn*

I. Introduction

Access management can be defined as the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway. Access Management helps to achieve the necessary balance between traffic movement and property access by careful control of the location, type, and design of driveways and street intersections

A significant part of access management focuses on the treatment of right turns along the roadway. Approaches used to achieve control of right turns include separation of the right turns in exclusive right turning lanes, use of U-turns either at or after the intersection and consolidation of median opening. The concept of U turns as an alternative to direct right turn movements is a relatively new approach and has recently been implemented in several locations. The safety gain from such a design is due to decrease in the number of conflicting points at the intersection. The advantages of U turn movements are

- Shorter travel times, reduced delay times and an enhancement in the roadway capacity.
- High right turn volumes at a signalized intersection requires right turn phases with long green times which may affect the intersection capacity and increases the delay of the through movements.

The increased U turn movements at signalized intersection may reduce the intersection capacity. In Kerala state the U turns are provided along with right turn movements. Currently, there is no widely accepted procedure for estimating the effects of U-turning vehicles on the capacity of a signalized intersection.

Saturation flow rate is one of the most critical factors in estimating the capacity of a lane or a lane group at signalized intersection. This study analyzed the effect of U turning vehicles on right turn saturation flow rate. Data regarding queue discharge time and U turning vehicles are taken and a second degree polynomial regression model was developed which estimated the relationship between average queue discharge time for each turning vehicle and varying percentage of U turning vehicles.

Effect of U turns on the capacity of signalized intersection was conducted by Pan Liu and Jian John in 2005 at Florida. In order to develop a procedure for estimating the effects of U-turning vehicles on left turn saturation flow rate, a pilot survey was conducted at the early stage of this study. An intersection with exclusive left turn lanes and protected signal phasing was selected for this survey. The study team recorded discharge headways for 138 left-turning vehicles and 54 U-turning vehicles in 27 left-turn queues during weekday peak hour.

The first headway was measured as the time between the initiation of the green signal and the crossing of the first vehicle over the stop line. The second headway was measured as the time between the first and second vehicles crossing the stop line. The collected data were classified into three categories based on different percentages of U-turning vehicles in left-turn lane. In this study, the determination of U-turn adjustment factors was achieved by analyzing the relationship between percentages of U-turning vehicles in the left-turn lane and the average queue discharge time for each turning vehicle. A regression model was developed to estimate the relationship between the varying percentages of U-turning vehicles in the left-turn lane and the average queue discharge time for each turning vehicle. It was found that three kinds of regression models were appropriate in describing the relationship, including linear regression model, linear regression model with exponential form, and the second-degree polynomial regression model. It is found that U-turning vehicles have considerable effect on the left turn saturation flow rate, and the effect increases with the increase of the percentage of U turning vehicles in the left-turn lane.

A study conducted by North Carolina State University in 1993 evaluated the effects of U turns on left-turn saturation flow rates. The study team selected four intersections with exclusive left-turn lanes and protected signal phasing and recorded saturation flow rates and U-turn percentages for 198 queues during weekday midday peaks. The data analysis showed that “a saturation flow reduction factor appears necessary for left-turn lanes that had large percentages of U-turns. The results of this study suggested tentative saturation flow reduction factors of 1.0 for U-turn percentages below 65, 0.90 for U-turn percentages between 65 and 85, and 0.80 for U-turn percentages exceeding 85

A study was conducted by Tsao and Chu in 1996. The study team recorded 600 headways of left turning passenger cars and 160 headways of U-turning passenger cars in Taiwan. This study revealed that the average headways of U-turning passenger cars are significantly larger than those of left turning passenger cars. The effects of U-turning vehicles depend upon the percent of U-turning vehicles in the left-turn lane, as well as the order of formation in the traffic stream

In present paper, an attempt has been made to establishing a relationship between the average queue discharge time and percentage of U turning vehicles and to develop a adjustment factor for estimating the capacity reduction. A regression model was developed and validation of the model was also done.

II. DATA COLLECTION

The present study was aimed at studying the effect of U turning vehicles at three signalized intersection in Trivandrum city, Kerala. For the present study, three signalised intersections selected in Trivandrum city.

- Karamana
- Over bridge
- Statue

The total queue discharge time and number of U- turning, number of right turning and number of through moving vehicles were collected from each intersection. The data from Karamana and Over bridge were used to develop the regression models and the data from Statue were used to validate the model. All the data were collected during peak hours in week days

A. The Total Queue Discharge Time

The discharge time required for each queue was measured in each intersection. It is measured as the elapsed time from the green signal was initiated until the rear wheel of the last vehicle in the queue crossed the stopped line. The discharged time for each queue in the green signal for continuous one hour was noted manually. The total queue discharged time was denoted as T in seconds. The details of total queue discharge time for each green time interval in Karamana intersection is shown in Table 1.

TABLE 1.DETAILS OF TOTAL QUEUE DISCHARGE TIME IN KARAMANA INTERSECTION

Green time interval	Total queue discharge time (sec)
1	8
2	3
3	8
4	13
5	19
6	13
7	8
8	34
9	13
10	20
11	10
12	12
13	10
14	11
15	14
16	17
17	23

The details of total queue discharge time for each green time interval in Over bridge intersection is shown in Table 2.

TABLE 2 .DETAILS OF TOTAL QUEUE DISCHARGE TIME IN OVERBRIDGE INTERSECTION

Green time interval	Total queue discharge time (sec)
1	22
2	28
3	27
4	34
5	31
6	20
7	19
8	35
9	23
10	19
11	33
12	29
13	40
14	35
15	41
16	37
17	39

From these tables it is clear that the total queue discharge time for Karamana intersection varies from 3 - 34 sec and that for Over bridge intersection varies from 19 - 41 seconds.

B. The number of vehicles

The total number of U turning vehicles and number of right turning vehicles were collected for one hour. In addition to that the numbers of through moving vehicles were also collected. The volume counts collected at each intersection are shown in Table 3.

TABLE 3.DETAILS OF VOLUME AT EACH INTERSECTION

Intersection	No. of U turning vehicles	No. of right turning vehicles	No. of through moving vehicles
Karamana	39	128	1112
Over bridge	65	765	1476
Statue	52	582	1246

C. Headways

Headway between the through moving vehicles, right turning vehicles and U turning vehicles were measured. When the green signal was initiated, headways between departing vehicles were observed as vehicles crossed the stop line. The first headway was measured as the time between the initiation of the green signal and the crossing of the first vehicle over the stop line. The second headway was measured as the time between the rear wheels of the first and second vehicles crossing the stop line. The signal timings at each intersection were collected. The details of the signal timings were shown in Table 4

TABLE 4 .DETAILS OF SIGNAL TIMINGS

Intersection	**Cycle time (sec)**
Karamana	95
Overbridge	184
Statue	89

III. **ANALYSIS**

The collected data was statistically analyzed to evaluate the effect of variable believed to have an effect on the average queue discharge time. The evaluated variable is the percentage of U turning vehicle in the desired signalized intersections. Regression analysis was used to evaluate the effect. It was done doing SPSS (Statistical Package for Social Science) software package and a model was obtained between the average queue discharge time and percentage of U turning vehicles

D. Analysis of data

1) Average queue discharge time

The average queue discharge time was calculated as the queue discharge time divided by the number of turning vehicles and through moving vehicles in the queue. It is represented as h in seconds. Average queue discharge time was calculated by using the equation

$$h = T / (N_u + N_r + N_t) \quad (1)$$

Where,

h = average queue discharge time for each turning vehicles (sec)

T = total queue discharge time(sec).

Nu = the number of U –turning vehicles in the queue

Nr = the number of right turning vehicles in the queue

Nt = the number of through moving vehicles in the queue

2) Percentage of U turning vehicles

The percentage of U turning vehicles in each queue was calculated by dividing the number of U turning vehicles in each signal timing to the sum of number of turning vehicles and number of through moving vehicles. It is expressed as percentage and it is given by the following equation

$$P_{UT} = N_U / (N_U+N_R+N_T) \quad (2)$$

Where,

P_{UT} = percentage of U turning vehicles in each queue

N_U = number of U turning vehicles

N_R = number of right turning vehicles

N_T = number of through moving vehicles

The average queue discharge time for Karamana intersections and the percentage of U turning vehicles are shown in the Table 5.

TABLE 5. .DETAILS OF AVERAGE QUEUE DISCHARGE TIME AND % OF U TURNING VEHICLES

Average queue discharge time(sec)	Percentage of U turning vehicles (%)
0.73	7.65
0.8350	8.3
0.5	5.23
0.394	3.03
0.792	7.12
0.6540	6.12
0.472	5.01
1.31	9.56
0.6630	6.12
0.61	5.69
0.32	3.27
0.48	4.62
0.303	3.7
0.41	3.48
0.48	4.55
0.586	5.45
0.958	8.74
0.475	4.28
0.67	5.6
0.33	3.33
0.577	5.43
0.45	3.45
0.387	3.23
0.393	3.57
0.571	4.76
0.36	3.21

The average queue discharge time for Over bridge intersections and the percentage of U turning vehicles are shown in the Table 6.

TABLE 6. DETAILS OF AVERAGE QUEUE DISCHARGE TIME AND % OF U TURNING VEHICLES

Average queue discharge time (sec)	Percentage of U turning vehicles (%)
0.4560	4.29
0.35	3.44
0.36	2.67
0.382	3.21
0.5210	5.61
0.5620	4.12
0.260	2.74
0.389	3.66
0.277	3.61
0.216	2.27
0.359	3.261
0.333	3.11
0.50	5
0.376	3.18
0.494	4.78
0.468	3.79
0.351	3.45

The collected data were classified into three categories based on different percentages of U-turning vehicles in left-turn lane. Within each category, the average discharge headways by different queue positions were calculated and listed in Table 7

TABLE 7. AVERAGE DISCHARGE HEADWAYS BY DIFFERENT QUEUE POSITIONS

P_{UTz}	Queue position	Range of discharge headways (sec)	Average queue discharge headways(sec)
$P_{UT} >$ 6 %	1	1.00-15.0	6.56
	2	2.0-6.0	4.11
	3	1.0-4.0	3.67
	4	1.0-6.0	3.89
	5	1.0-4.0	3
	6	1.0-4.0	2.78
	7	1.0-4.0	2.11
	8	1.0-4.0	2
$3< P_{UT} <$ 6 %	1	1.0-10	4.5
	2	1.0-8.0	2.64
	3	1.0-5.0	2.58
	4	1.0-9.0	2.38
	5	1.0-6.0	2.38
	6	1.0-7.0	2.33
	7	1.0-4.0	2.18
	8	1.0-4.0	1.96
$0< P_{UT} <$ 3 %	1	1.1-8.0	4
	2	1.0-9.0	3.37
	3	1.0-5.0	3.25
	4	2.0-5.0	3
	5	2.0-4.0	2.75
	6	2.0-3.0	2
	7	1.0-3.0	1.75
	8	1.0-3.0	1.7

The queue discharge patterns for the queue with different percentage of U turning vehicles were shown in Fig 1.

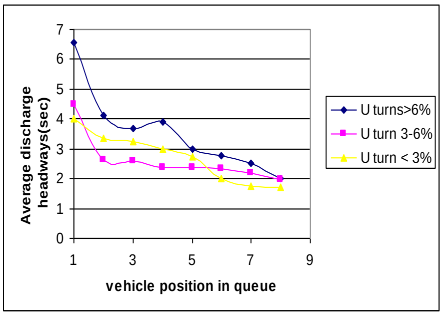

Figure 1. The queue discharge patterns for varying % of U turning vehicles

From the figure it is clear that the average discharge headway increases with the percentage of U-turning vehicles. This could be explained by the factor that the turning characteristics of U-turns and right-turns are different. U-turn movement has shorter turning radius than that of right-turns. Consequently, it may have lower turning speed. As a result, U-turning vehicles may consume more of the available green time and more of the lane's available capacity as compared with right-turns. In addition, field observation found that there is a conflict point between U-turning vehicles and the following right-turning vehicles. When a vehicle is making a U-turn at a signalized intersection, the following right-turning vehicles sometimes have to make a break due to the speed difference. This may cause the headways of the following right-turning vehicles to be large; and this increase must be considered in the overall capacity reduction due to U-turns.

E. Model Development

The collected data were analyzed with average queue discharge time for each turning vehicle as the dependent variable and the varying percentages of U-turning vehicles as the independent variable. Several regression models were considered and regression results were compared. The models such as linear regression model, linear with exponential, second degree polynomial regression model, inverse function, power function and logarithmic function are used to develop a relation between average queue discharge time and percentage of U turning vehicles. The results of the various analysis are shown in Table 8

TABLE 8. RESULTS OF REGRESSION ANALYSIS

Sl No	Regression model	R^2 value	F value
1	Linear	0.873	398.52
2	Logarithmic	0.812	250.27
3	Inverse	0.694	131.79
4	Power	0.863	364.34
5	Exponential	0.844	313.24
6	Second degree polynomial	0.880	209.10

F-test was conducted at 5% level of significance and a degree of freedom of 58

From the analysis it was found that the second degree polynomial regression model has the best regression results with R2 value of 0.880 and the model was statistically significant. The developed average queue discharge time model as

$$h = 0.003258 \ P_{UT}^{\ 2} + 0.0698 \ P_{UT} + 0.267 \qquad (3)$$

Where,

h = average queue discharge time for each turning vehicle

P_{UT} = Percentages of U-turning vehicles

The collected data are plotted with average queue discharge time for each turning vehicle as the dependent variable and the varying percentages of U-turning vehicles as the independent variable. The average queue discharge time is plotted on Y axis and percentages of U-turning vehicles on X axis and the relation is as shown in Fig. 2.

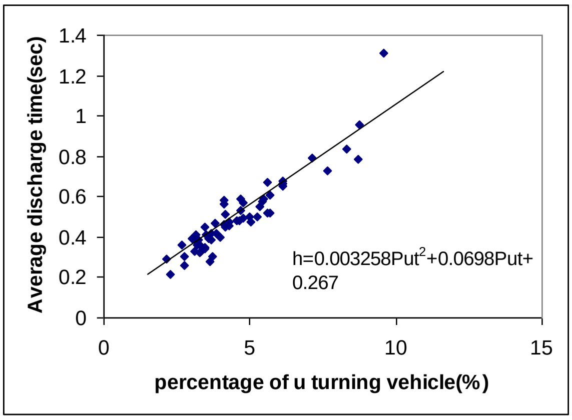

Figure 1. Relation between average queue discharge time and percentage of U turning vehicle

This graph shows that there is a best relation between the dependent and independent variables and the curve is best fit for the second degree polynomial regression equation with a R^2 value of 0.880

F. Adjustment factor

When right-turning vehicles are mixed with U-turning vehicles the discharge flow rate does not display an easily identifiable steady maximum rate. Therefore, traditional "headway method", which measures the saturation headway of U-turning vehicles and left-turning vehicles in the field, may not be suitable for estimating the effects of U-turning vehicles on traffic stream U turn adjustment factor for varying percentages of U turning vehicles were calculated by using the developed model. For finding out the adjustment factor the equation used as

$$f_{UT} = h_0 / h = 0.267/(0.003258\ P_{UT}^2 + 0.0698\ P_{UT} + 0.267) \qquad (4)$$

Where

f_{UT} = U turn adjustment factor

P_{UT} = Percentages of U-turning vehicles

h = average queue discharge time (sec)

h_0 = base average queue discharge time (sec)

The adjustment factor for varying percentage of U turning vehicles are shown in the Table 9.

TABLE 9. DETAILS OF THE ADJUSTMENT FACTORS FOR VARYING PERCENTAGES OF U TURNING VEHICLES

P_{UT} (%)	**f_{UT}**
1	0.7852
1.5	0.7044
2.0	0.6363
2.5	0.5781
3.0	0.5280
3.5	0.4844
4.0	0.4462
4.5	0.4126
5.0	0.3828
5.5	0.3563
6.0	0.3325
6.5	0.3111
7.0	0.2917
7.5	0.2742
8.0	0.2582
8.5	0.2437
9.0	0.2304
9.5	0.2181
10.0	0.2068

U-turning vehicles have considerable effect on the saturation flow rate, and the effect increases with the increase of the percentage of U turning vehicles in the right-turn lane. For example, the U-turn adjustment factor for the queue with 5 % of U-turning vehicles is 0.38, which implies a 62% capacity reduction in the approach flow.

G. Validation of Model

The developed model was validated using Chi-square test. Chi-squared test is one of the simplest and most widely used non-parametric tests in statistical work. The formula for computing Chi-square value is

$$\chi 2=(O-E)^2/E \quad (5)$$

Where

O is the observed frequency

E is the expected or theoretical frequency.

The calculated value of Chi-square is compared with the table value for given degrees of freedom at specified level of significance.

For validation the data collected from another signalised intersection i.e Statue junction in Trivandrum city. Total queue discharge time and the traffic volume were collected at the junction and the average queue discharge time and percentage of U turning vehicles were estimated by substituting the values in the model developed. The observed field data are shown in the Table 10 .

For performing the Chi-square test on the data collected the null hypothesis was set up as there is a significant effect of number of U turning vehicles on the average queue discharge time. And the alternate hypothesis was set up showing no significant relationship

TABLE 10. OBSERVED AND ESTIMATED VALUES AT STATUE JUNCTION

Observed avg queue discharge time	Estimated avg.queue discharge time	Chi-square value
0.73	7.85	0.0803609
0.84	8.55	0.0622728
0.65	6.23	0.0383834
0.47	4.92	0.0697596
0.67	6.52	0.0422108
0.52	5.88	0.0923167
0.71	7.68	0.0817454
0.49	4.98	0.0606708
0.38	3.69	0.062736
0.4	4.35	0.0853321
0.63	6.32	0.0517444
0.71	7.65	0.079988
0.39	3.87	0.0655122
0.27	2.69	0.0907402
0.89	8.77	0.0508703
0.54	5.65	0.066364
	$\sum$	1.0810075

The Chi-square value from the statistical table obtained at 5% level of significance and 15 degree of freedom is 24.996 .Hence from the test, it is clear that the calculated value is smaller than the table value which leads to the acceptance of the null hypothesis selected showing that the model is valid for finding the influence of U turning vehicles on the average queue discharge time at signalised intersection. The test gave a significant relationship between average queue discharge time and percentage of U turning vehicles

IV. CONCLUSIONS

The conclusions obtained from the present study are:

- U-turning vehicles adversely impact the capacity of signalized intersections; and the effect increases with the increase of the percentage of U-turning vehicles in the approach flow.
- A model was developed by taking average queue discharge time as depended variable and percentage of U turning vehicles as independent variable and it is statistically significant with a R2 value of 0.882.
- Capacity reduction due to varying percentage of U turning vehicles was found out by developing adjustment factors.
- Validation of the model was done using Chi-square test and a significant relationship between average queue discharge time and percentage of U turning vehicles obtained.

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