Effects of U-Turns on Left-Turn Saturation Flow Rates

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As more U-turning vehicles use a left-turn lane, the saturation flow rate of the lane may become significantly lower. However, the 1985 *Highway Capacity Manual* (HCM) does not account for U-turns in calculating the capacity of a left-turn lane group at a signalized intersection. To determine whether a U-turn factor should be included in a revised HCM analysis method, a preliminary study was conducted at North Carolina State University. 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 have large percentages of U-turns. *T*-tests and regression models indicated that saturation flow rates were significantly lower when queues had more than 65 percent U-turns. However, the analyses also showed no correlation between saturation flow and the percentage of U-turns for queues with 50 percent or fewer U-turns. The analysis was inconclusive between 50 and 65 percent U-turns because of small samples. The results suggest 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 follow-up investigation should focus on intersections that have high percentages of U-turns, restrictive geometry, or high percentages of U-turning heavy vehicles.

As traffic volumes continue to increase, states construct more roads that are divided by medians. One of the primary purposes of a median is to improve road safety by redirecting large volumes of left turns into driveways. Arterials lined with restaurants, stores, and other businesses tend to experience many accidents involving vehicles that attempt left turns across heavy traffic. By dividing a road with a median, some potential customers must proceed to the next crossover or intersection and make a U-turn. As a result, U-turn volumes are increasing at signalized intersections.

As more U-turning vehicles use a left-turn lane, the saturation flow rate for the lane may become significantly lower. However, the 1985 *Highway Capacity Manual* (HCM) (*1*) does not account for U-turns in calculating the capacity and level of service of a left-turn lane group at a signalized intersection. Because major revisions are planned for the operational model and method of analyzing signalized intersections in the HCM, the question arises: Should a U-turn factor be included when adjusting for left turns?

To help answer that question, a team from the Department of Civil Engineering at North Carolina State University (NCSU) conducted a preliminary study to determine the impact of U-turns on the saturation flow rate of left-turn lanes. A secondary objective of the study was to develop tentative U-turn adjustment factors derived from the percentage of U-turns at an intersection approach, should the need for an adjustment factor be evident. The team selected four intersections in Raleigh, North Carolina, for study. Each intersection had an exclusive left-turn lane with protected signal phasing and significant U-turn volumes. The study team recorded saturation flow rates and the percentage of U-turns for 198 queues. These data were then statistically analyzed to determine the effects of U-turning vehicles on the saturation flow rates of left-turn lanes. In this paper the current resources available to analyze the problem are briefly discussed, the study method is described, and the results from the data analysis are presented.

CURRENT RESOURCES

The 1985 HCM uses saturation flow rates for lane groups to determine the capacity and level of service at signalized intersections. The analysis of left-turn movements is one of the most important components of the signalized intersection analysis procedure. The 1985 HCM determines saturation flow by modifying a suggested ideal saturation flow rate. Currently, the manual recommends 1,800 passenger cars per hour of green time per lane (pcphgpl); however, it is likely that this value will be revised upward. Analysts modify this ideal by applying adjustment factors that describe nonideal traffic and roadway conditions. The left-turn adjustment factor accounts for the fact that left-turn movements are not made at the same saturation flow rate as through movements. There are eight left-turn adjustment factors, which are categorized by the number of turn lanes, type of phasing, and type of lane (exclusive or shared). For exclusive single and dual left-turn lanes with protected phasing, the adjustment factors are constant values of 0.95 and 0.92, respectively. The 1985 HCM does not include comment on how these adjustment factors were derived. However, these values were most likely developed from observed saturation headways of vehicles operating in exclusive left-turn lanes with protected phasing. The HCM does not give adjustment factors for left-turn lanes that accommodate a large number of U-turning vehicles. The 1985 HCM encourages users to measure saturation flow directly in the field when unique conditions are encountered. Unfortunately, many local agencies do not have the resources to conduct saturation flow studies, and high U-turning volumes are not unique in many areas.

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An on-line search of the Transportation Research Information Service, along with on-line and manual searches of the NCSU library, revealed no published studies that directly address the effects of U-turns on protected left-turn saturation flow rates for single or dual lanes. *A Policy on Geometric Design of Highways and Streets* (*2*) provides guidance for the geometric design of intersections to accommodate U-turns but does not discuss U-turn capacity.

STUDY METHOD

To gain a preliminary understanding of the relationship between U-turns and left-turn saturation flow, the study team collected data at four intersections for which significant volumes of U-turns are made from exclusive left-turn lanes controlled by protected signals. Saturation flow rates and the percentages of U-turns were collected for individual queues of traffic. The study team also collected general information describing intersection layout at the study sites. The study needed data from the field because current traffic simulation packages are inadequate for analyzing the effect of U-turns on left-turn lanes. Exclusive left-turn lanes with protected signals make up the vast majority of locations in North Carolina where significant volumes of U-turns are found. If this preliminary study convinces the profession of the need for an adjustment factor developed from the percentage of U-turns, other signal and lane conditions may also be of interest in other states.

The measure of effectiveness used in this study was the saturation flow rate for the left-turn lane. The study team adapted a data collection sheet from the forthcoming *Manual of Transportation Research Studies* (*3*) for collecting saturation flow manually using a stopwatch. The study team adopted this method because it provided quick, accurate measurements of saturation flow and percentages of U-turns. The sheet was modified so that observers could record which vehicles in the queue made U-turns. Figure 1 displays the data collection sheet used in the study. For each observation, the observer circled the number on the form that corresponded to the queue position of each vehicle that made a U-turn. The observer started the stopwatch when the rear axle of the fourth vehicle in the queue crossed the stop bar and stopped the watch when the rear axle of the last stopped vehicle in the queue crossed the stop bar. Extensive studies of left-turn lanes have shown that headways stabilize after the fourth vehicle in the queue. Vehicles that joined the back of the queue after the signal had turned green were not included in the data collection. Observers did not record queues of six or fewer vehicles. For queues of more than 10 vehicles, the watch was stopped as the 10th vehicle crossed the stop bar. This reduced the chance that the green left-turn signal would expire before observers could record a time. Because times were always recorded when vehicles had green left-turn signals, ending lost time was not an issue.

The study team considered more than a dozen Raleigh-area sites for data collection. Prospective sites needed to have a median dividing the roadway, exclusive left-turn lanes, protected signal phasing, an approach grade of nearly 0 percent, an intersection angle of about 90 degrees, at least two lanes to receive the U-turns, limited left-turn and U-turn truck volumes, and adequate left-turn and U-turn volumes. Initially, the team wanted to collect data at both single and dual exclusive left-turn lanes with protected phasing. Unfortunately, no dual left-turn lanes examined satisfied the study requirements. The study team conducted short-turning movement counts at eight potential sites during peak volume periods. After these counts, the team selected the best four intersections for data collection. These intersections included Western Boulevard and Kent Road, Glenwood Avenue and Duraleigh Road, Capital Boulevard and Millbrook Road, and Capital Boulevard and Spring Forest Road.

Table 1 provides descriptions of the chosen sites. The study team measured the width of receiving areas for Intersections 2, 3, and 4 from the right edge of pavement to the yellow line that marked the inside shoulder. Medians were measured from yellow line to yellow line. Intersection 1 had a curbed concrete median, so the receiving area and median widths were measured from curb to curb. The sites were in suburban areas, and the major roads at each site were lined with businesses that generate U-turning traffic. Each intersection had a left-turn-lane storage length capable of holding 10 or more vehicles. Bus operations were not an issue at any of the intersections. Right turns on a red signal were legal from the minor streets at all intersections. Each intersection had three lanes available to receive U-turning traffic except for Intersection 1. However, Intersection 1 had a 3.66-m (12-ft) paved right shoulder that created a receiving width comparable to those of Intersections 2, 3, and 4. All the intersections were generally flat with the exception of Intersection 2, which had an approach grade of approximately −2 percent (i.e., downhill) at the stop bar.

The team collected data during eight weekdays in July 1992 at the midday peak between 11:00 a.m. and 2:30 p.m. The midday peak periods had large volumes of left-turning and U-turning traffic at the sites. The weather on data collection days was clear and pavements were dry. Recorded queues consisted only of passenger vehicles and light trucks. Observers ignored queues that had buses, trucks with more than four tires, motorcycles, or vehicles with trailers. Also, queues in which unusual events occurred, such as a right turn on red from the minor street that blocked U-turns or an uncharacteristically slow vehicle, were not considered. Adams collected most of the data, although Hummer collected some data at the intersection of Western Boulevard and Kent Road. The observer stood close enough to the intersection to clearly see the lane being observed, the stop bar, and the signal indication, but was generally not visible to turning drivers. Upon completion of the data collection, the field information was transferred to a computer data file that was analyzed using Version 6.07 of the Statistical Analysis System software (*4*).

RESULTS

During data collection, the observers noted some general perceptions concerning left-turn and U-turn traffic. First, the observers noted that few conflicts occurred between right-on-red movements from the minor street and U-turn vehicles, even though there were usually vehicles ready to turn right on red. On a few occasions, large trucks turned right on a red signal and obstructed U-turn traffic. These observations

Intersection: ______________________________

Approach: ______________________________

Lane Type: ______________________________

Time: ______________ Date: ______________

Obs. No.	Time (seconds) between 4th vehicle and ...				
	7th veh.	8th veh.	9th veh.	10th veh.	U-turn positions
1					1 2 3 4 5 6 7 8 9 10
2					1 2 3 4 5 6 7 8 9 10
3					1 2 3 4 5 6 7 8 9 10
4					1 2 3 4 5 6 7 8 9 10
5					1 2 3 4 5 6 7 8 9 10
6					1 2 3 4 5 6 7 8 9 10
7					1 2 3 4 5 6 7 8 9 10
8					1 2 3 4 5 6 7 8 9 10
9					1 2 3 4 5 6 7 8 9 10
10					1 2 3 4 5 6 7 8 9 10
11					1 2 3 4 5 6 7 8 9 10
12					1 2 3 4 5 6 7 8 9 10
13					1 2 3 4 5 6 7 8 9 10
14					1 2 3 4 5 6 7 8 9 10
15					1 2 3 4 5 6 7 8 9 10
16					1 2 3 4 5 6 7 8 9 10
17					1 2 3 4 5 6 7 8 9 10
18					1 2 3 4 5 6 7 8 9 10
19					1 2 3 4 5 6 7 8 9 10
20					1 2 3 4 5 6 7 8 9 10

FIGURE 1 Data collection sheet used to record field observations.

TABLE 1 Intersection Descriptions

Intersection	Major St.	Minor St.	Intersection Angle (degrees)	Width of Receiving Area (m)	Curb and Gutter (yes/no)	Approach Lane Width (m)	Median Type	Width of Median (m)	% Grade of Approach	Dist. Stop Bar from Nose (m)
#1	Western Blvd.	Kent Rd.	90	10.97	yes	3.66	concrete	2.44	0	0
#2	US70	Duraleigh Rd.	90	11.28	yes	3.66	grass	6.10	-2	0
#3	Capital Blvd.	Millbrook Rd.	90	14.02	yes	3.66	grass	5.79	0	0
#4	Capital Blvd.	Spring Forest Rd.	90	14.02	yes	3.66	grass	5.49	0	0

1 m = 3.28 ft

were interesting but not kept in the data base. Second, pedestrians did not conflict with left-turning or U-turning traffic during data collection. Intersection 1 had the most pedestrian traffic and was the only intersection with pedestrian-crossing indicators. Intersection 1, however, produced only one pedestrian conflict that disrupted left-turn traffic flow during about 5 hr of data collection. This observation was not included in the data base. Finally, observers noted that U-turning trucks significantly influenced the saturation flow of left-turn lanes. The observers only recorded queues consisting of passenger vehicles for this study; however, left-turn lanes with significant U-turn truck traffic may warrant further investigation.

The first step of the analysis was to calculate the saturation flow rate and the percentage of U-turns for each observed queue. Saturation flow was easily calculated by converting the recorded times into vehicles per hour. The study team had several options available to determine which vehicles to include when computing the percentage of U-turns, however. The team could have computed the percentage of U-turns using the vehicles in queue Positions 1 through the last recorded vehicle in the queue (n), Positions 1 through $n-1$, Positions 4 through n, or Positions 4 through $n-1$. To determine the preferred option, the team first addressed the issue of whether U-turns made in the first three positions of the queue significantly affected saturation flow measured for Vehicles 4 through n. The study team calculated the mean saturation flows associated with queues that had zero, one, two, or three U-turn movements in the first three queue positions. Table 2 gives these means by intersection. For cases in which sample sizes allowed meaningful comparisons within an intersection, the team conducted t-tests between groups of observations with different numbers of U-turns. The results of these t-tests indicated that no two means were significantly different from each other at the 95 percent confidence level. Therefore, the study team chose to define the beginning of the queue with the fourth vehicle.

The next question in deciding how to calculate the percentage of U-turns was whether to include the last vehicle recorded. A U-turning vehicle could affect saturation flow by slowing before it reaches the stop bar or by causing the vehicle behind it to slow. If only the latter effect is important, the last vehicle in the queue should not be included when computing and analyzing the percentage of U-turns. The study team believed, on the basis of field observations, that both effects are important and that the last vehicle should be included. To verify this belief, the study team calculated mean saturation flows for each intersection for queues where the last vehicle did or did not make a U-turn, as shown in Table 3. The mean saturation flow is lower at all four intersections when the last vehicle made a U-turn, and t-tests at the 95 percent confidence level showed a significant difference between the means for Intersection 4. The study team therefore computed the percentage of U-turns from Vehicle 4 through the last observed vehicle.

The study team observed a total of 198 queues at the four intersections. Figures 2 through 5 show scatter diagrams of saturation flow versus the percentage of U-turns for each intersection. Table 4 provides a summary of key left-turn lane statistics by intersection. A mean saturation flow of 1,589 pcphgpl at Intersection 1, which is lower than other sites, may be attributed to a curbed median, a narrower side street, more local traffic, and other reasons. Mean saturation flow rates at Intersections 2, 3, and 4 do not differ greatly from each

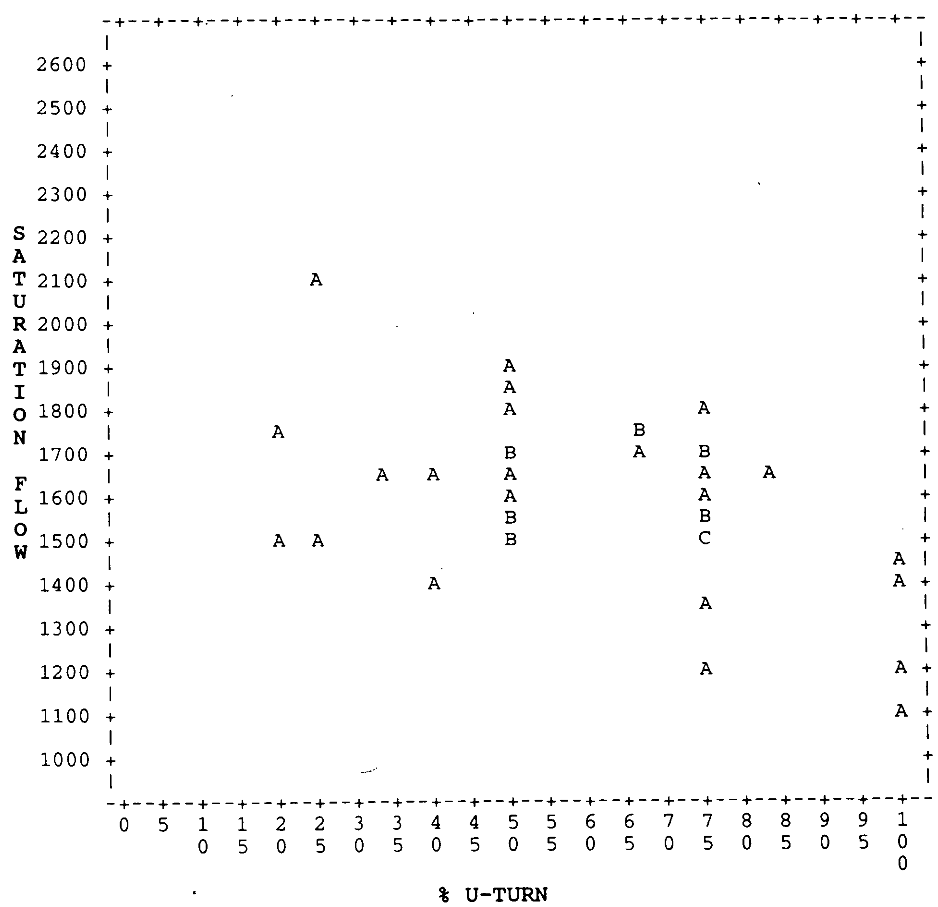
TABLE 2 Summary Statistics for U-Turns Made in First Three Queue Positions

INTERSECTION	# U-TURNS MADE IN FIRST 3 QUEUE POSITIONS	# OBS.	MEAN SATURATION FLOW (pcphgpl)	STANDARD DEVIATION
1	0	2	1764	204
	1	7	1531	156
	2	16	1569	189
	3	13	1617	219
2	0	12	1710	180
	1	18	1861	229
	2	15	1921	191
	3	4	1843	166
3	0	28	1877	176
	1	13	1776	202
	2	5	1819	340
	3	-	-	-
4	0	39	1838	231
	1	15	1835	266
	2	11	1944	261
	3	-	-	-

NOTE: The symbol "-" indicates that data were not available.

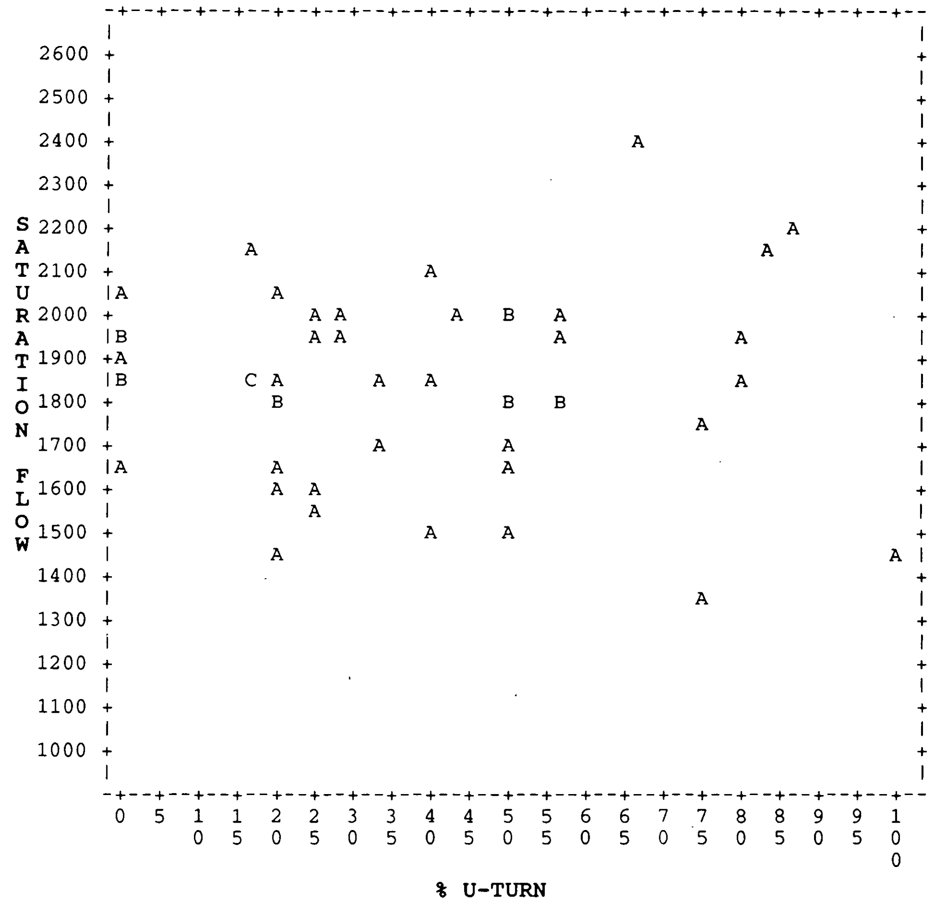
TABLE 3 Summary Statistics for Queues in Which Last Vehicle Did and Did Not Make a U-Turn

INTERSECTION	LAST VEHICLE MAKING U-TURN? (yes/no)	# OBS.	MEAN SATURATION FLOW (pcphgpl)	STANDARD DEVIATION
1	no	15	1631	176
	yes	23	1561	204
2	no	30	1865	206
	yes	19	1803	221
3	no	39	1854	214
	yes	7	1773	133
4	no	47	1915	238
	yes	18	1699	185



NOTE: A = 1 obs., B = 2 obs., etc.
Saturation flow measured in pcphgpl.

FIGURE 2 Scatter diagram for Intersection 1.



NOTE: A = 1 obs., B = 2 obs., etc.
Saturation flow measured in pcphgpl.

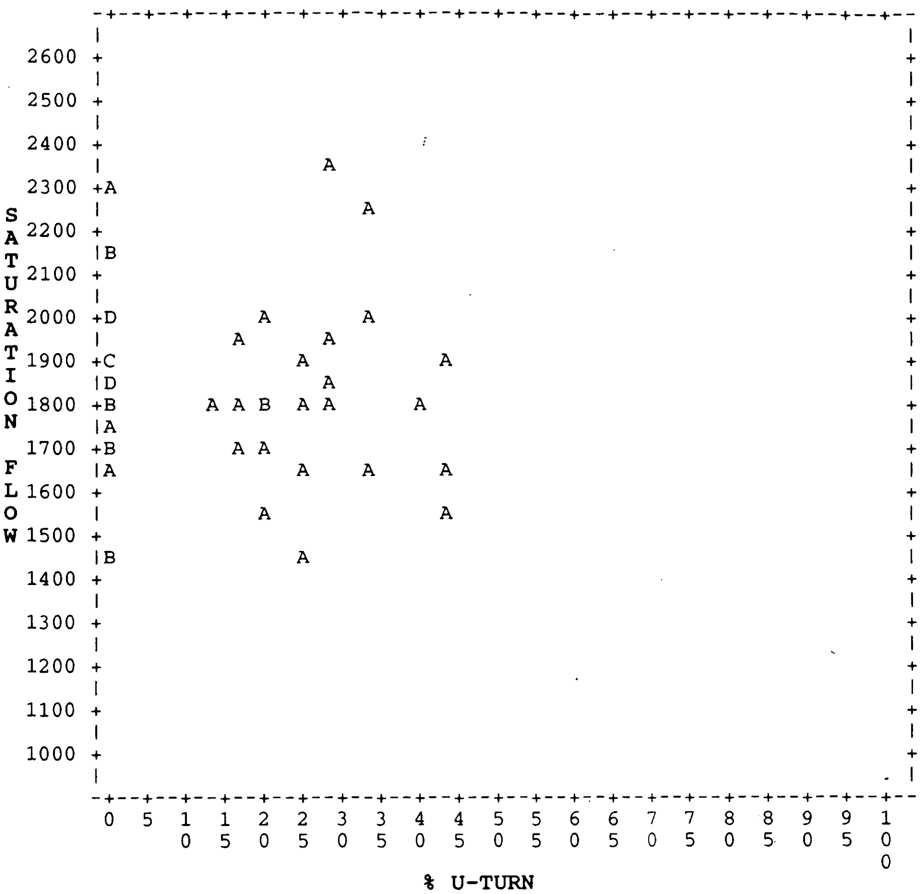
FIGURE 3 Scatter diagram for Intersection 2.

other. Intersections 1 and 4 had wide ranges for the percentage of U-turns, but at Intersection 3, 43 percent was the maximum percentage of U-turns for any queue.

Simple linear regression was used to model the relationship between saturation flow and U-turn percentage. The study team chose simple linear regression over other model forms because of a desire for a simple model consistent with other models in the HCM and a visual inspection of the scatter diagrams. Although there is theory relating saturation flow rates to other nonideal conditions, the study team found no theory on the form of the relationship of saturation flow to the percentage of U-turns. Table 5 gives results of the simple linear regression analysis for each intersection. The simple linear regression models generally showed a poor correlation between saturation flow and the percentage of U-turns. Intersections 1 and 4 had the highest correlation with adjusted R^2 values of 0.20 and 0.14, respectively. In addition, for Intersections 1 and 4 the slopes of the regression lines were negative and the coefficients were significantly different from zero at the 95 percent level according to *t*-tests. These findings suggest that saturation flow tends to decrease as the percentage of U-turns increases. Intersection 3, with a maximum percentage of U-turns less than 50, showed no correlation between saturation flow and the percentage of U-turns (adjusted $R^2 = 0.0141$).

On the basis of visual inspection of Figures 2 through 5 and the fact that no correlation existed for Intersection 3 (for which the maximum percentage of U-turns was less than 50), the study team applied simple linear regression with 50 percent U-turns as a break point. Table 6 gives the results for each intersection for which the percentage of U-turns was less than or equal to 50. Adjusted R^2 values for each intersection indicate that no correlation existed when the percentage of U-turns was less than or equal to 50. Also, the coefficients of the U-turn percentage variable (i.e., the slopes of the regression lines) were not significantly different from zero at the 95 percent level according to *t*-tests. This indicates that there is little change in saturation flow rate as the percentage of U-turns increases from 0 to 50.

Table 7 gives the results of the regression analysis for which the percentages of U-turns were greater than 50 percent. Intersection 3 was not analyzed because only queues with fewer than 50 percent U-turns were observed. Regression analysis on Intersection 2 data indicated no correlation between saturation flow and the percentage of U-turns (adjusted $R^2 = -0.0457$). Analysis of Intersections 1 and 4 showed a stronger



NOTE: A = 1 obs., B = 2 obs., etc.
Saturation flow measured in pcphgpl.

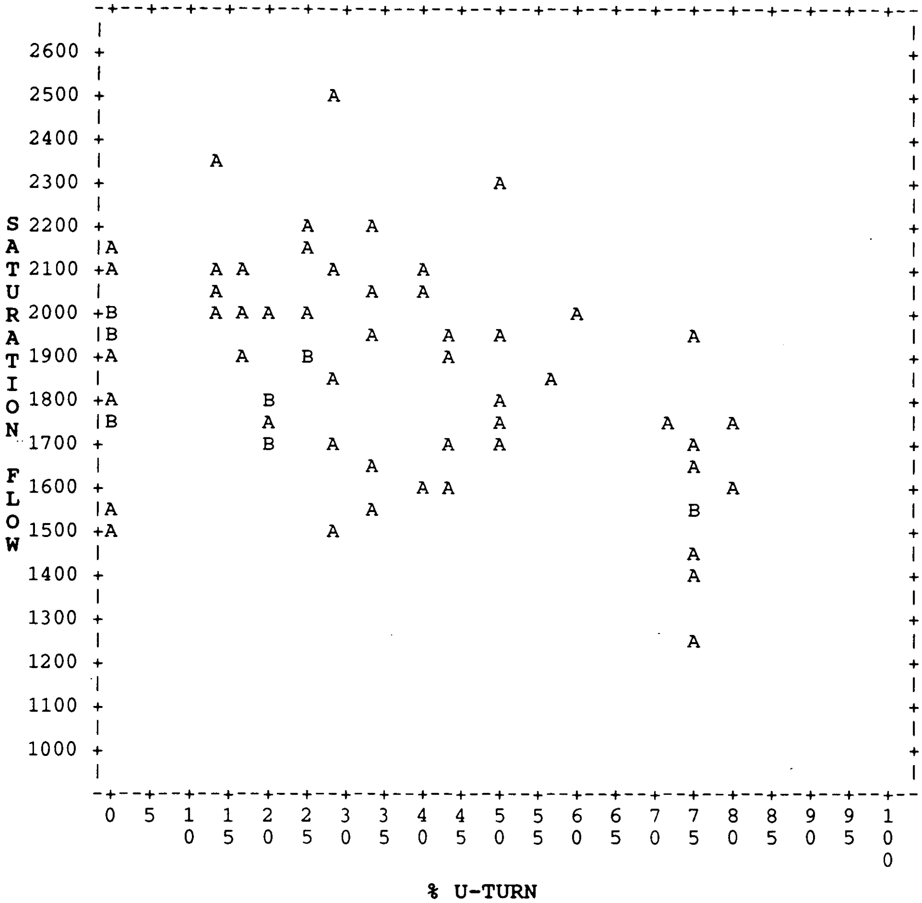
FIGURE 4 Scatter diagram for Intersection 3.

correlation between saturation flow and the percentage of U-turns than in other analyses with adjusted R^2 values of 0.39 and 0.19, respectively. Slopes of -15.4 for intersection 4 and -11.2 for Intersection 1 indicate that saturation flow decreases as U-turns increase beyond 50 percent.

To better understand the data, the study team divided the data set into five separate groups by the percentage of U-turns. The data were grouped on the basis of the results of the linear regression analyses and a visual inspection of the scatter diagrams in Figures 2 through 5, as follows:

1. 0 to 29 percent,
2. 30 to 50 percent,
3. 51 to 65 percent,
4. 66 to 85 percent, and
5. 86 to 100 percent.

Table 8, which is a summary of *t*-tests, gives the mean saturation flow rates of each group within each intersection at the 95 percent confidence level. Intersection 1 showed no significant difference among Groups 1, 2, and 4, although Group 4 had a lower mean than Groups 1 and 2. Group 5, however, was significantly different from the other groups. Group 3 was not analyzed for Intersection 1 because the study team did not record any queues for which 51 to 65 percent U-turns were observed. For Intersection 2 there were no significant differences between any of the groups, although the analysis was hampered because Groups 3, 4, and 5 had small sample sizes. Other reasons why saturation flow did not decrease with the percentage of U-turns could be attributed to the downgrade approach and the width of the cross street that allowed left-turning vehicles to quickly bypass U-turning vehicles. Because the maximum percentage of U-turns was less than 50 for Intersection 3, only Groups 1 and 2 were compared using the *t*-test. The test revealed no significant difference between the two groups. The analysis of Intersection 4 showed no significant difference between Groups 1, 2, or 3. Group 4, however, was significantly different from Groups 1, 2, and 3. Generally for all the intersections, *t*-tests showed no significant differences between Groups 1 and 2. This result confirms the results produced by the regression analysis for 50 percent or lower U-turns. Because of limited sample sizes, *t*-tests for Group 3 were inconclusive. Groups 4 and 5 were shown to be significantly different from other groups at Intersections 4 and 1, respectively, and indicates that saturation flow decreases as U-turns increase above 65 percent.



NOTE: A = 1 obs., B = 2 obs., etc.
Saturation flow measured in pcphgpl.

FIGURE 5 Scatter diagram for Intersection 4.

TABLE 4 Summary of Key Left-Turn Lane Statistics by Intersection

INTERSECTION	# OBS.	MEAN SATURATION FLOW (pcphgpl)	SAT. FLOW STDEV	MIN. SATURATION FLOW (pcphgpl)	MAX. SATURATION FLOW (pcphgpl)	MEAN %U-TURN	%U-TURN STDEV	MIN. %U-TURN	MAX. %U-TURN
1	38	1589	194	1121	2122	62	22	20	100
2	49	1841	212	1367	2381	37	26	0	100
3	46	1842	204	1444	2328	14	15	0	43
4	65	1855	244	1262	2515	33	25	0	80

TABLE 5 Linear Regression Results for Percentage of U-Turns between 0 and 100

INTERSECTION	DEGREES OF FREEDOM	ESTIMATED CONSTANT	CONSTANT STANDARD ERROR	ESTIMATED X COEFF.	X COEFF. STANDARD ERROR	ADJUSTED R-SQUARE	Significant at 95% level using t-test? CONSTANT	X COEFF.
1	37	1844.11	84.57	-4.15	1.30	0.20	yes	yes
2	48	1838.21	53.46	0.07	1.18	-0.02	yes	no
3	45	1859.52	41.80	-1.25	2.04	-0.01	yes	no
4	64	1982.29	46.78	-3.83	1.13	0.14	yes	yes

TABLE 6 Linear Regression Results for Percentage of U-Turns Less Than or Equal to 50

INTERSECTION	DEGREES OF FREEDOM	ESTIMATED CONSTANT	CONSTANT STANDARD ERROR	ESTIMATED X COEFF.	X COEFF. STANDARD ERROR	ADJUSTED R-SQUARE	Significant at 95% level using t-test? CONSTANT	X COEFF.
1	17	1700.99	163.60	-1.07	3.77	-0.06	yes	no
2	36	1862.79	55.2	-1.47	1.81	-0.01	yes	no
3	45	1859.52	41.80	-1.25	2.04	-0.01	yes	no
4	51	1919.79	54.62	-0.48	1.93	-0.02	yes	no

TABLE 7 Linear Regression Results for Percentage of U-Turns Greater than 50

INTERSECTION	DEGREES OF FREEDOM	ESTIMATED CONSTANT	CONSTANT STANDARD ERROR	ESTIMATED X COEFF.	X COEFF. STANDARD ERROR	ADJUSTED R-SQUARE	Significant at 95% level using t-test? CONSTANT	X COEFF.
1	19	2413.44	245.21	-11.17	3.07	0.39	yes	yes
2	11	2220.63	467.88	-4.55	6.32	-0.05	yes	no
3	-	-	-	-	-	-	-	-
4	12	2764.11	577.53	-15.39	7.89	0.19	yes	no *

NOTE: The symbol "-" indicates that data were not available.
* Significant at 90% level.

TABLE 8 Summary of *T*-Tests Comparing Mean Saturation Flow Rates of Each U-Turn Percentage Group

INTERSECTION	GROUP	# OBS.	MEAN SAT. FLOW (pcphgpl)	SAT. FLOW STDEV	GROUPS WITH SIGNIFICANTLY DIFFERENT MEANS (95% LEVEL)
1	1	4	1714	294	5
	2	14	1639	141	5
	3	-	-	-	-
	4	16	1586	155	5
	5	4	1296	155	1, 2, 4
2	1	24	1838	179	none
	2	13	1802	195	none
	3	4	1898	106	none
	4	6	1905	349	none
	5	2	1821	503	none
3	1	39	1844	201	none
	2	7	1830	240	none
	3	-	-	-	-
	4	-	-	-	-
	5	-	-	-	-
4	1	35	1928	227	4
	2	17	1868	218	4
	3	2	1904	105	4
	4	11	1594	185	1, 2, 3
	5	-	-	-	-

NOTE: The symbol "-" indicates that data were not available.

SUMMARY AND CONCLUSION

In this preliminary study, the primary objective was to investigate the impact of U-turns on left-turn-lane saturation flow. The secondary objective was to develop saturation flow adjustment factors on the basis of the percentage of U-turns, should the need for such factors be proven. Saturation flow rates and the percentages of U-turns were recorded for exclusive, single left-turn lanes with protected phasing at four intersections in Raleigh, North Carolina. Data were collected on weekdays between 11:00 a.m. and 2:30 p.m. Queue lengths for saturation flow measurements varied from 7 to 10 vehicles and the queues that were measured contained no buses, trucks, motorcycles, or trailers. The study team calculated the percentage of U-turns on the basis of the fourth vehicle to the last observed vehicle in the queue.

From the analysis, a saturation flow reduction factor appears necessary for left-turn lanes with a large percentage of U-turns. *T*-tests at the 95 percent confidence level between mean saturation flow rates for observations grouped by the percentage of U-turns show significant differences when U-turns are greater than 65 percent. In addition, simple linear regression models had large negative slopes, which supported a decrease in saturation flow with more than 50 percent U-turns. *T*-tests and linear regression analyses provided strong evidence that no correlation between saturation flow and the percentage of U-turns exists for 50 percent or fewer U-turns. The analysis was inconclusive between 50 and 65 percent U-turns because of the small samples in this study. The break point at which the percentage of U-turns starts to be a significant factor may occur in this region.

The study results suggest tentative saturation flow reductions of about 10 percent for U-turn percentages between 65 and 85 and 20 percent for U-turn percentages exceeding 85. Reductions of 10 and 20 percent equate to U-turn adjustment factors of 0.9 and 0.8, respectively. Saturation flow reductions of 10 and 20 percent are in line with the analysis of group means described in this paper and are somewhat conservative compared with the regression line slopes for observations with more than 50 percent U-turns. These reductions are suggestions developed from small sample sizes, and analysts should await further research before applying them.

Although the adjustment factors suggested in this study were derived from observations of single left-turn lanes, the results may also apply to dual left-turn lanes. Currently the 1985 HCM computes the saturation flow for exclusive dual left-turn lanes by multiplying an ideal saturation flow of 1,800 pcphgpl by the number of turn lanes and a dual left-turn lane adjustment factor of 0.92. On the basis of the results presented in this paper, suggested correction factors for dual left-turn lanes are 5 percent for 65/2 percent U-turns and 10 percent for 85/2 percent U-turns.

This preliminary study demonstrated that further investigation into the impact of U-turns on left-turn saturation flow is warranted. One major and surprising finding from this study was that there was little variation in saturation flow observed when the U-turn percentage was 50 or less. A future follow-up study should focus on intersections that have high percentages of U-turns. Other situations worth attention include intersections with a large percentage of U-turning trucks, U-turns from dual left-turn lanes (to verify that the suggestions given are valid), and U-turns into narrow receiving areas or across narrow medians.

ACKNOWLEDGMENT

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