INVESTIGATING THE ADJUSTMENT FACTOR FOR PROTECTED LEFT TURNS FROM A SHARED LANE

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The purpose of this paper is to propose a more accurate method for the estimation of the left-turn adjustment factor for protected left turns at traffic signals. Research on the left-turn adjustment factor for two-lane approaches with protected left turns from a shared lane, gave results that differ from those of the HCM. Based on extended field measurements, the model proposed in this paper relates the left-turn adjustment factor for protected left turns from a shared lane to a number of traffic parameters. Such as the distribution of vehicles in the lanes, the mean volume per lane and the proportion of the left-turning vehicles.

Key Words: Left turn, Shared lane, Traffic signals

1. INTRODUCTION

A traffic network consists of junctions and links. In a junction area, the way the conflicting volumes are served is one of the most determining factors for the efficient operation of the urban network. Junctions should not necessarily be signalized. In contrast, the accommodation of great volumes in a non-signalized junction would cause undesirable delays. In such cases, signalization is more preferable, in order to serve traffic in a more efficient way.

Signalization of junctions is the most common characteristic of the traffic network in an urban area. The Highway Capacity Manual[1] indicates a special procedure for the estimation of the way a signalized junction operates. The concepts of capacity and level of service are central to the analysis of intersections. Capacity at intersections is defined for each approach and is related to traffic, roadway, signalization conditions and to the concept of saturation flow[3,6]. The computation of saturation flow is based on the determination of the ideal saturation flow and the values of each of the adjustment factors for non-ideal conditions. The adjustment factor for left turns[2,4,5] is of great importance in the determination of the saturation flow and is related to whether left turns are executed on a protected or a permitted phasing and whether they are accommodated in an exclusive left-turn lane or in a shared lane. The way protected left turns are confronted in the HCM releases a hint that further analysis and elaboration may be needed, in order to achieve more reliable results.

2. THE 2000 HCM MODEL

According to the HCM methodology for signalized intersections, saturation flow is defined as follows :

$$S = So*N*fw*f_{HV}*fg*fbb*fa*f_{RT}*f_{LT}$$

where:

- S = prevailing saturation flow rate in the lane group, vphg;
- So = ideal saturation flow rate per lane, pcphgpl;
- N = number of lanes in the lane group;
- fw = adjustment factor for lane width;
- f_{HV} = adjustment factor for heavy vehicles;
- fg = adjustment factor for grade;
- fp = adjustment factor for parking;
- fbb = adjustment factor for local bus blockage;
- fa = adjustment factor for area type;
- f_{RT} = adjustment factor for right turns;
- f_{LT} = adjustment factor for left turns.

For protected left turns made from a shared lane, the HCM determines the left-turn adjustment factor f_{LT}, as a function of the proportion of left turns in the lane group flow.

The left-turn adjustment factor is defined as follows:
$f_{LT} = 1/(1+0,05P_{LT})$,
where:
P_{LT} = the proportion of left turns in the lane group flow.

The HCM indicates that the proportion of left turns in the lane group flow has a range of values from 0 to 1. In practice, though, a value of 1 for P_{LT} concludes that 100% of the vehicles in the lane group are left-turners. In this case, it is obvious that left turns are made by vehicles using any lane of the group. Such a case, where left-turners dominate the shared and through lanes on an exclusive basis, is not reasonable to happen and as a result a value of 1 for the proportion of left turns in the lane group has no practical meaning. Furthermore, high volumes of left-turning vehicles are preferably served by an exclusive left-turn lane in order to avoid delays. A shared left-turn lane is capable of achieving efficient operation of the intersection, in cases where a low percentage of left turns exists. Therefore, the assumption of P_{LT} ranging from 0 to 1 may not reflect the existing conditions on the operation of intersections, as it seems to be incompatible with reality and an upper limit seems to exist for the value of P_{LT} for a lane group with a shared left-turn lane.

The way f_{LT} is estimated by the HCM seems to demand further investigation on another point, as well. Impeditive effect (blockage) of through vehicles in a shared left-turn lane is increasingly recognized. Through vehicles using the shared lane can be blocked by a left-turning vehicle which has stopped on the red light of the approach, while there is still a green light for through movement. The HCM assumes that through movement blocked by a left-turning vehicle continues being blocked until the left-turning vehicle frees the shared lane. In practice, though, a great proportion of through vehicles, moving in the shared lane, move to the adjacent through lane, in order to avoid being blocked. Impedance is imposed on the through lane flow, in a way which indicates that left turners have an influence on through lane operation, as well.

The objective of this research is to analyze, in the detail required, the junction operation, when there are left-turn movements that share the lane with the through traffic. More specifically, the calculation of the saturation flow for the lanes of the approach serving such movements is examined and the way saturation flow is related to traffic movements is analyzed.

3. FIELD MEASUREMENTS

The objective of the research is to evaluate the accuracy of the HCM in order to calculate the left-turn adjustment factor. As described above, through vehicles using a shared lane move to the adjacent lane in order not to be blocked by left-turning traffic. In this case, an impact on the flow of the adjacent lane is imposed. Less impact is imposed on the nearest to pavement lane in the case of three-lane approaches. For approaches with more than two lanes, left turns are not in general served by a shared lane. In such cases, there is an exclusive left-turn lane for the accommodation of the left-turning traffic, so that lower values for delays and higher flow-rate values are achieved. Further, the overwhelming majority of multilane cases in which shared-lane groups exist have two lanes. Therefore, research was limited to two-lane approaches.

For the calculation of the saturation flow the headway ratio method was applied. As a result, during field measurements the data, described below, per cycle and per lane was recorded. The number of vehicles passing the stop line of each lane was counted, in order to calculate the volume of each lane. The headways between successive vehicles as they cross the stop line were calculated, and the type of each vehicle was recorded. The proportion of vehicles which moved from the shared lane to the though lane due to the existence of at least one left-turning vehicle blocking the shared lane was calculated. The proportion of the effective green time of through movement during which the shared lane was blocked was calculated, as well. In addition, two more information hints were recorded. The first one refers to vehicles crossing the junction in the through lane and is related to whether vehicles originated from the shared lane or not. The second one refers to vehicles crossing the junction in the shared lane and is related to the kind of movement the vehicles executed (going straight or turning left).

The data collected by the field measurements was used for the calculation of the prevailing saturation flow in order to estimate the factors the left-turn adjustment factor depends on.

4. ANALYSIS OF RECORDED VALUES

As already mentioned, the main objective of this work is the more accurate estimation of the left-turn adjustment factor on the case of protected left turns made by a shared lane. The calculation of the saturation flow using the headway ratio method is preceding the calculation of the left-turn adjustment factor. The data sample used for the determination of the saturation flow was not the whole data collected by the field measurements, but a great part of it. The estimation of the saturation flow by the headway ratio method presumes the conversion of vehicles to passenger car units (pcu). In order to simplify the procedure it was critical to determine whether vehicles need to be converted to pcu or not. It would be more convenient for the computations to avoid this conversion. As already known, a light commercial vehicle is equivalent to one pcu value. In order to avoid conversions to pcu values, by use of doubtful conversion values, only the cycles with passenger cars were used as a data sample. At this point of analysis, it would be necessary to emphasize the fact that the cycles that were not included in the data sample constitute a small proportion of the data collected by the field measurements, as the proportion of medium and heavy commercial vehicles, as well as buses was negligible. In addition, cycles of the data collected where U-turning vehicle existed were excluded from the data sample, because U-turns incur greater delays and therefore a U-turner cannot be assumed to influence the junction operation in the same way a left-turner does.

As already mentioned, the estimation of the left-turn adjustment factor presumes the calculation of the saturation flow from the data that were selected as a sample. The saturation flow is calculated by the headway ratio method and equals the reverse of the sum of the mean saturated headway for each lane. The question that appears straightforward is which is the value of the headway that is critical and operates as an upper limit for the saturated headways. Headways between successive vehicles in queue are certainly saturated. These headways are taken under consideration for the estimation of this upper value for the saturated headways. For the computation of this upper limit value the first two gaps, when the signal turns to green, were omitted, while the headways between the 4th and the last vehicle in queue were taken into consideration. The first two gaps are not corresponding to saturated headways, due to lost time. The flow is considered saturated after the 4th vehicle crosses the stop line, while there is no more lost time.

An upper limit of the saturated headways was estimated for the through lane and for the shared lane, respectively. Specifically, for the shared lane four different values for this upper limit were calculated, one for each of the combinations of the movements that took place

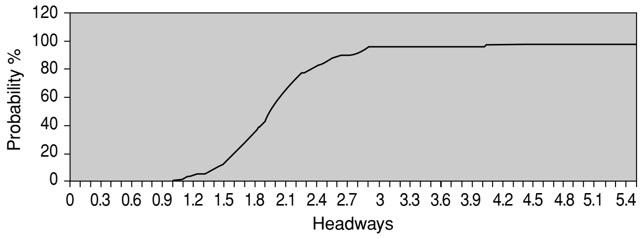

Fig. 1 Distribution of gaps for the through lane

(Vehicle going straight - vehicle going straight, vehicle going straight - left-turner, left-turn - vehicle going straight, left-turner - left-turner).

Figure 1 shows the form of the curve from which the upper limit of saturated headways for the through lane was estimated.

The upper limit of the saturated headway is the value of the headway after which the curve becomes almost horizontal. The mean saturated headway was calculated for each lane and each cycle of the data sample. Each lane's saturation flow is the reverse of the mean saturated headway for this lane. The saturation flow of the approach is the sum of each lane's saturation flow.

This work aims at determining the parameters the left-turn adjustment factor depends on for the protected left turns made by a shared lane. The calculation of the saturation flow was demanded for the estimation of the left-turn adjustment factor.

5. PREDICTION OF THE LEFT TURN ADJUSTMENT FACTOR

The 2000 HCM specifies an analytically developed model for determining the saturation flow. This model was used vice versa in this research for the estimation of the left-turn adjustment factor and the parameters it depends on. According to the headway ratio method, the saturation flow could be estimated if the mean saturated headways were known for each lane.

The value of the saturation flow is given by the following formula:

$$S = [(1/MG\text{-}_{through}) + 1/(MG\text{-}_{shared})] * 3600,$$

where :

S = the saturation flow

$MG\text{-}_{through}$ = the mean gap of the vehicles in saturated flow, that passed the through lane's stop line;

$MG\text{-}_{shared}$ = the mean gap of the vehicles in saturated flow, that passed the shared lane stop line.

The left-turn adjustment factor was determined by the formula indicated in the HCM for the prediction of the prevailing saturation flow. Adjustments for non-ideal conditions were applied as indicated in the HCM. The value used for the ideal saturation flow was different from the value proposed in the HCM. The value of So = 2100pcphgpl was adopted as was estimated by the National Technical University of Athens (NTUA) field measurements for Greece.

A value for the left-turn adjustment factor f_{LT} for each cycle was calculated by the formula suggested in the HCM, as the values of the other adjustment factors as well as the values of the ideal and the prevailing saturation flows were already estimated.

Regression on the independent variables was applied [7] in order to have a model calibrated for the estimation of the left-turn adjustment factor.

The calibrated model, as derived from the regression procedure, is:

$$f_{LT} = 3.845 - 3.211*(A) + 9.555*10^{-7}*(B) - 9.42*10^{-2}*(C) -0.108*(D)$$

$$R^2 = 0.491$$

The volumes expressed by the independent variables that were entered in the model are shown in Figure 2.

where :

A = the square of the ratio of the volume of vehicles moving in the shared lane (Q1 in Figure 2) (before their passing to the adjacent through lane) to the total volume of the approach [(Q1+Q2) in Figure 2];

B = the square of the mean per lane volume [(Q1+Q2)/2 in Figure 2)];

C = the square root of the volume of the through lane without counting any vehicles originating from the shared lane (Q2 in Figure 2);

D = the ratio of the left-turning volume (Qa in Figure 2) to the shared lane's volume (Q1 in Figure 2).

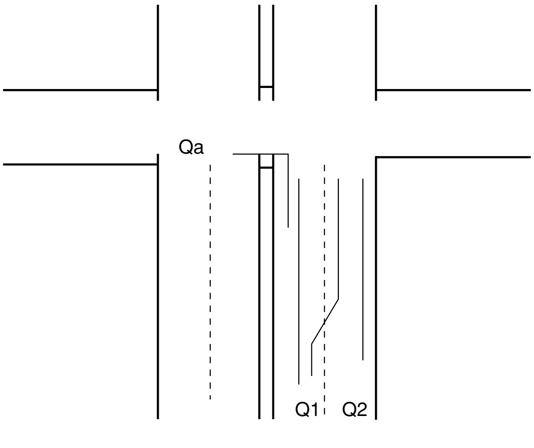

Fig. 2 Protected shared left-turn intersection and the measured volumes denotation

The volumes entered in the formula derived from the regression procedure are expressed in thousands of vehicles per hour (1000vph).

The regression procedure has concluded to the model described and the independent variables entered are expressing reality sufficiently enough. The independent variables entered the equation were selected as the most preferable among plenty of others, such as all the volumes that could be measured and a combination of them including all the reasonable products and ratios that could be estimated. A sample of independent variables, used in the calibration, was:

* the proportion of through lane vehicles that was derived from the shared lane;
* the proportion of the green phase for the through movement during which the shared lane was blocked;
* the ratio of left-turning vehicles to the through ones for the shared lane;
* the ratio of through movement of the shared lane to through movement of the through lane.

The values of the standard error of the coefficients corresponding to the independent variables that entered the equation, as well as the t-Student distribution values and the significance of the above factors are shown in Table 1.

Table 1 Coefficient values for the proposed model

	Coefficient Value	Std. Error	t	Sig.
(Constant)	3.845	0.831	4.628	0.000
A	-3.211	0.980	-3.275	0.003
B	$9.555*10^{-7}$	0.000	2.282	0.030
C	$9.42*10^{-2}$	0.030	-3.096	0.004
D	-0.108	0.096	-1.130	0.267

The model has a reasonable correlation coefficient and expresses a logical relationship. However, it should be mentioned that its validity has been checked only for the data range, i.e. flows range from 750 to 1100 vph.

Furthermore, the equation expresses the factors the left-turn adjustment factor depend on, and as a result it is reasonable to include at least one factor that refers to left turns. As a result, it should be mentioned that factor D is one of minor significance, but it was forced to enter the equation, as it is the only one that deals with left-turning volume.

In conclusion, the model for the calculation of the left-turn adjustment factor may not reflect reality in an absolute way, but it is of great importance to compare the f_{LT} value of the HCM, and the f_{LT} value of the calibrated model with the f_{LT} value as it is derived from field measurements.

In this analysis, in order to achieve this comparison the average error of the f_{LT} value for the HCM and the average error of the predicted f_{LT} value was computed as:

$$(\text{Average Error})_{(HCM)} = \{[(f_{LT(ACT)} - f_{LT(HCM)})] / (n-1)\}^{1/2}$$

$$(\text{Average Error})_{(PRED)} = \{[(f_{LT(ACT)} - f_{LT(PRED)})] / (n-1)\}^{1/2}$$

where :

$f_{LT(ACT)}$ = field-measured value of the left turn adjustment factor;

$f_{LT(HCM)}$ = value of the left turn adjustment factor estimated by the HCM model;

$f_{LT(PRED)}$ = value of the left turn adjustment factor estimated by the model being tested;

n = number of samples.

The results of this analysis for f_{LT} are presented in Table 2 and shown in Figure 3.

The proposed regression model is considerably more accurate than the analytic model of the 2000 HCM in predicting f_{LT}.

Table 2 Average error in prediction of f_{LT}

	2000 HCM	PROPOSED MODEL
Aver. Error	12.6 %	5.4 %

6. CONCLUSIONS AND RECOMMENDATIONS

This paper analyzes the impact of left turns on through traffic, where they share a common lane and recommends another formula for calculating the left turn adjustment factor for the determination of the saturation flow rate. Several findings are significant.

In the 2000 HCM model, for the calculation of the left-turn adjustment it is not directly determined whether it refers to the approach, considering both the through and the shared lane as a lane group, or it refers only to the shared lane, which serve the left-turning movement. As derived from the field measurements, through movement of the shared lane, try to pass to the through lane, in order to avoid being blocked by left-turning vehicles, which wait at the red phase of the traffic signals, while the through movement is still served. As a result, left-turning vehicles have an influence on the through-lane movement, and the calculation of the left-turn adjustment factor should not be based only on the shared lane, but both on the shared and the through lane, considering the approach as a lane group.

The left turn adjustment factor f_{LT} is not strictly related to the proportion of the left turns in the lane group, as recommended in the HCM model. This research concluded that three additional factors affect the accuracy of

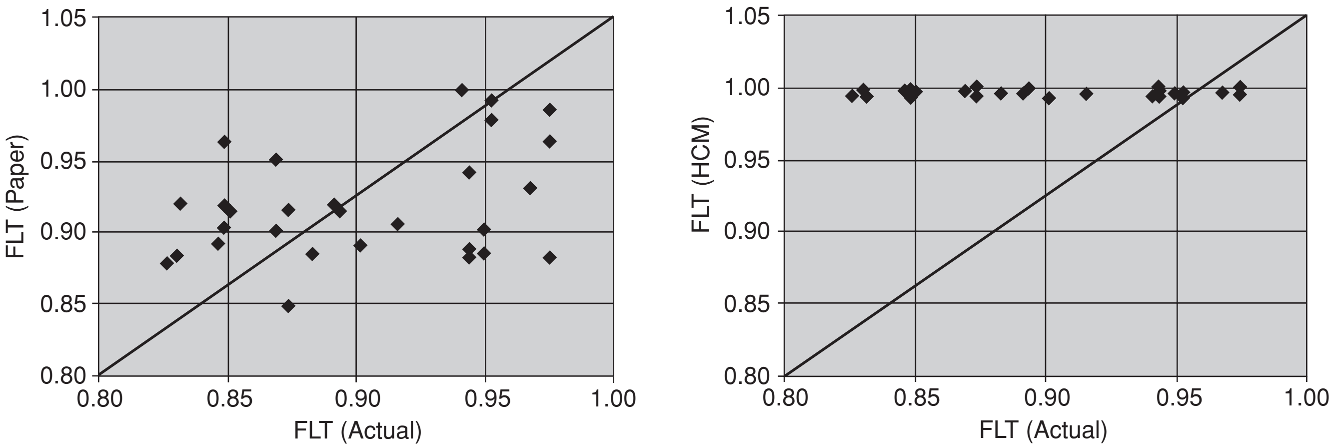

Fig. 3 Comparative accuracy of f_{LT} prediction

the calculation of the left-turn adjustment factor. These additional factors are the mean volume per lane, the distribution of vehicles in the lanes, and the through lane's volume measured at a cross-cut before the passage of vehicles of the shared lane to the adjacent through lane. The third factor controls the grade of difficulty for this passage of shared lane vehicles to the through lane. Vehicles passing from the shared to the through lane to avoid being blocked by left-turners, as has already been justified, leads to the demand of considering both lanes as a lane group. The volume of these vehicles cannot easily be measured, but in no case should be excluded from the f_{LT} estimation formula. The third additional factor mentioned, which influence the f_{LT} estimation, reflects the influence of this volume on the f_{LT} value.

In the 2000 HCM model the proportion of left turns in the lane group ranges from 0.00 to 1.00, reflecting clearly unrealistic traffic conditions, as already mentioned. It should be mentioned that on the basis of the data sample collected, values exceeding 0.25 would reflect rather abnormal traffic conditions and as a consequence, they may be ignored.

The results of this research refer only to two-lane approaches, considering both the shared and the through lane as one lane group, assuming that left-turners influence the through lane's movement, as well. Research on three-lane approaches with protected left turns made by a shared lane may not conclude to the same results. On such approaches, a fact of great importance is whether the left-turning movement influences the right lane, which is not the one adjacent to the shared and therefore, whether the approach should be considered as a single lane group. Furthermore, the impact of a high percentage of heavy vehicles in the traffic stream more analytically investigated.

Approaches serving left turns with a shared lane on a protected phasing are not as seldom as considered. Therefore, an extended research should be carried out in order to develop a more general formula for the estimation of the left-turn adjustment factor that would be applicable in any intersection.

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