Journal of Civil Engineering
The Institution of Engineers, Bangladesh
Vol. CE 29, No. 2, 2001

A SIMPLE MODEL TO ESTIMATE LEFT-TURN, SAME-DIRECTION, REAR-END TRAFFIC CONFLICTS AT UNSIGNALIZED INTERSECTIONS ON RURAL HIGHWAYS

Tanweer Hasan[1]

ABSTRACT: A simple model to estimate the hourly same-direction, rear-end conflicts due to left-turns at unsignalized intersections on rural 2-lane and 4-lane highways is developed in this study. The variables required to use the model are approach traffic volume, turning volume, roadway operating speed, and turning speed of left-turn vehicles. Statistical tests showed that the model performs reasonably well in predicting the traffic conflicts experienced by the following through vehicles due to left-turn maneuvers. Apart from its applicability in developing guidelines for treating left-turn traffic at unsignalized intersections on rural highways, this model also can be used to identify the locations with high probability of rear-end accidents due to left turns.

KEYWORDS: Rear-end conflicts, left-turn, unsignalised intersections, rural highways.

INTRODUCTION

Left-turn, rear-end, same-direction conflicts occur when a lead vehicle reduces its speed considerably below the average roadway operating speed leaving the following through vehicles to brake or swerve to avoid a rear-end collision. On high-speed highways, the frequent occurrence of traffic conflicts of this type may even lead to fatal crashes. To reduce the occurrence of traffic conflicts as ell as to eliminate the delays that may cause to the through vehicles due to the deceleration of the left-turning vehicles, different treatments in terms of turning lanes are provided at the intersections.

However, guidelines used by highway agencies for treating the left-turn traffic are mainly based on experience and engineering judgement (Hasan/996). The actual impacts of left-turning traffic on through vehicles are not known. Again, since left-turns are more critical than right-turns, much less attention has been paid to the left-turning traffic. Therefore, there is a need to develop a model that can estimate the impact of left-turning traffic on the through vehicles.

FORMULATION OF THE MODEL

As postulated by Mounce (Mounce 1983), a left-turn, rear-end conflict on a two-lane rural highway can be seen as a result of

---

[1] Department of Civil Engineering, BUET, Dhaka 1000, Bangladesh

occurrence of several of events at the same time. The events are, i) for any two vehicles, the lead vehicles is a turning vehicle, ii) the headway between these two vehicles is such that due to the declaration of the lead vehicle, the following vehicle must reduce its speed to avoid a collision, and iii) the following vehicles is a through vehicle. On a four-lane highway, in addition to these three events, a fourth event that the available gap in the inner lane in is not acceptable for lane change for the following through vehicle traveling in the outer lane must occur.

The first event refers the likelihood that the lead vehicle of any two vehicles will make a left turn. Assuming that the left-turns are made from the outer lane, this binomial process can be estimated as follows

$$Pturn = \frac{Vturn}{\alpha V} \qquad (i)$$

where P_{turn} = probability of a left turn, αV = traffic volume in the outer lane (*veh/hr*), V_{turn} = left traffic turn volume (*veh/hr*), and α is a factor which corresponds to the proportion of total traffic volume traveling in the outer lane. The value of α is equal to 1 for 2-lane highways and is less than 1 for 4 –lane highways.

The second event concerns the time headway, T_A required between two vehicles such that no reduction in speed will be incurred by a through vehicle immediately behind a left-turning vehicle. This headway is assumed to be of sufficient length to allow the following vehicle to maintain roadway operating speed to within a 2-second headway of the lead vehicle while the lead vehicle decelerates to complete a left-turn (see Fig. 1). Any headway less than the critical headway will result in a left-turn, same direction conflict (i.e., the following vehicle must brake or swerve to avoid a rear-end collision). Under conditions of random flow, the probability of a left-turn, same direction conflict is

$$P_{conflict} = P(t \le T_A) = 1 - e^{-a\upsilon T_A} \qquad (ii)$$

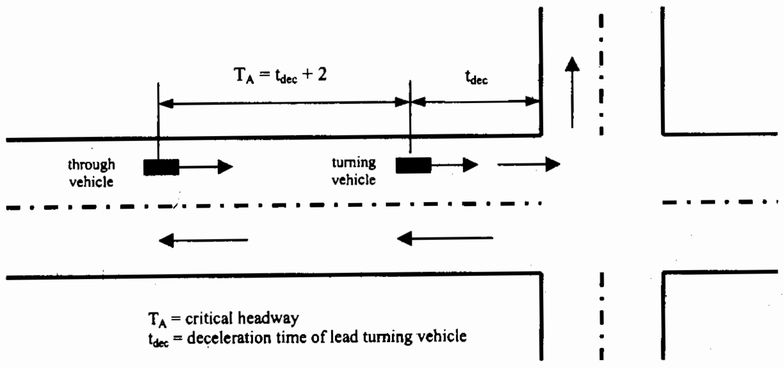

Fig1. Critical headway, T_A

where $P_{conflict}$ probability of a speed reductin for the following through vehicle, αv = traffic volume in the outside lane (veh/sec) = $\alpha V/3600$, T_A = critical headway (sec) and e = base of the natural logarithms.

The probability that he following vehicle of any two vehicles will be a though vehicle ($P_{Through}$) is simply

$$P_{through} = 1 - P_{turn} \qquad (iii)$$

If the events described by equations (i) through (iii) are assumed to be independent, then the probability (P_T) that any following through vehicle will be involved in a left-turn same direction conflict is simply the product of the three probabilities P_{Turn}, $P_{conflict}$ and $P_{Through}$, as shown below

$$P_T = P_{turn} \times P_{conflict} \times P_{through} \qquad (iv)$$

The product of the total probability function (P_T) and the traffic volume in the outside lane (αV) provides an estimate of the number of conflicts per hour ($n_{conflict}$) experienced by through vehicles immediately behind a left turning vehicle:

$$n_{impact} = P_T \times aV \qquad (v)$$

where n_{impact} = total number of immediate-following vehicles in the outside lane that are affected by left-turn maneuvers (veh/hr).

The equations proposed by Mounce do not account for the possibility of lane changing by immediately following vehicles on four-lane highways. Therefore, the basic equations must be restricted to two-lane highways. In the case of four-lane highways, the distribution of headways in the outer lane and gaps in the inner lane may result in situations where a vehicle in the outside lane may change lanes due to the lead decelerating vehicle without reducing its speed and without causing any impact on the vehicles in the inner lane. Therefore, on four-lane highways the immediately following thorough vehicle will be impacted when the prevailing situation is such that it cannot change lanes to avoid slowing behind a left turning vehicle.

The probability that the following through vehicle will not be able to change lanes without reducing its speed depends on the availability of a critical gap, T_B in the inner lane (see Fig. 2). This gap depends on the headway between the vehicles moving in the inner lane. Therefore, when the gap is less than T_B, the following through vehicle in the outer lane will not be able to change lanes and thus will slow down despite the availability of another lane in the same direction and will wait for a suitable gap. The probability of impact on four-lane highways is thus

$$P_{conflict} = P(t \leq T_A \cap t \leq T_B) = (1 - e^{-\alpha v T_A})(1 - e^{-(1-\alpha) v T_B}) \qquad (vi)$$

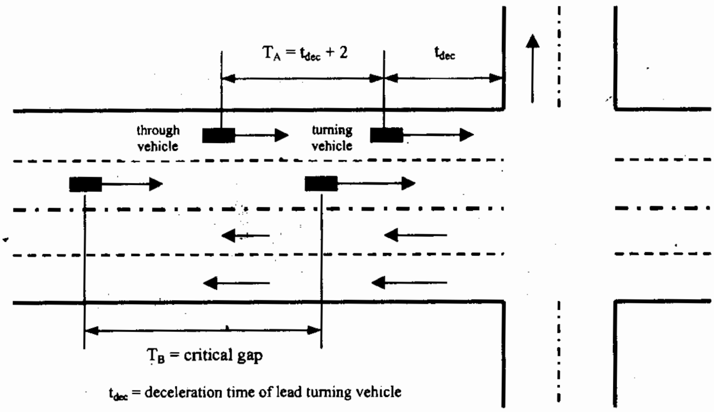

Fig 2. Critical gap, T_B in the case of 4-lane highways.

where αv = traffic volume in the outer lane (*veh/sec*), $(1-\alpha\alpha)v$ = traffic volume in the inner lane (*veh/sec*), T_A = critical headway (*sec*), and T_B = critical gap (*sec*).

Therefore, in the case of four-lane highways, P_T and n_{impact} in equations (iv) and (v) can be calculated using the expression for $P_{conflict}$ in equation (vi).

Equations (i) through (vi) provide an estimate of the number of conflicts per hour experienced by through vehicles immediately behind a left-turning vehicle. The equations do not, however, provide and estimate of the effects of these initial conflicts on subsequent vehicles in the traffic stream. In many cases, the distribution of headways will result in situations where the effects of conflicts experienced by vehicles immediately behind a left-turning vehicle propagate back through the traffic stream.

To account for the effects of this conflict induced shock wave on the traffic stream, a factor EI (extent of impact) can be used to estimate the total number of vehicles, including the immediate following vehicle, that are likely to experience a conflict (i.e., speed reduction) caused by a left-turning vehicle as follows:

$$N_{impact} = P_T \times aV \times EI \qquad (vii)$$

where N_{impact} = total number of vehicles in the outside lane that are affected by left-turn maneuvers (*veh/hr*). Equation (vii) is applicable for both two-lane and four-lane highways because all the equations are based on the vehicular movements in the outer lane.

ESTIMATION OF KEY VARIABLES

Critical Headway, T_A

Consider the case of an unsignalized intersection on a highway with a operating speed of 60 kmph (16.67 *m/sec*). Assuming a left-turn speed of 25 kmph (6.94) *m/sec*) and a uniform deceleration rate of −1 m/sec^2, the time (t_{dec}) required by a turning vehicle to decelerate from normal operating speed to 25 kmph can be determined from the familiar speed-time relationship:

$$t_{dec.} = \frac{u - u_o}{f} = \frac{6.94 - 16.67}{-1} = 9.73\ sec$$

where u = final speed (*m/sec*), u_o = initial speed (*m/sec*), and f = decleration rate (m/sec^2). In this case, the speed of the following vehicle will be affected by the decleration of the lead vehicle when the time headway (T_A) between the lead vehicle and the following vehicle is less than t_{dec} +2 sec, or 11.73 sec. the values of T_A for various speeds are as follows:

Critical Gap, T_B

The critical gap, T_B introduced in the formulation of the model for four-lane roadways may be defined as the headway between the vehicles in the inner lane which will allow the vehicle in the outer lane to execute a lane-change without reducing its speed and without causing any impact (i.e., speed reduction) on the vehicles moving in the inner lane.

Drew (Drew 1968) describes the "theoretical minimum ideal gap" required by merging vehicles in a ramp-freeway connection. Such a gap is made up of three time intervals: (1) a safe time headway between the merging vehicle and the freeway vehicle ahead, (2) the time lost accelerating during the merging maneuver, and (3) a safe time headway between the second free way vehicle and the merging vehicle. the safe headway referred to is that headway between two vehicles in a lane which will allow the following vehicle to stop safely even if the vehicle in front makes an emergency stop.

The time intervals (1) and (3) are the safe stopping sight distance corresponding to the speed of the vehicles. as mentioned earlier, T_B is a gap which ill allow the immediate following vehicle to execute a lane-change without reducing its speed. Therefore, time interval (2) in Draw's model is not applicable under the assumptions postulated in the model formulation. In addition to the time intervals (1) and (3), a perception-reaction time should be added. The perception-reaction time is higher than the brake reaction time employed in case of stopping. A suitable value can be selected considering the decision sight distance needed for a driver to detect and unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard, select and appropriate speed and path, and initiate and complete the required maneuver safely and efficiently. Because decision sight distance gives drivers additional margin for error and affords them sufficient length to maneuver their vehicles at the same or reduced speed rather than to just stop, its values are substantially greater than stopping sight distance (AASHTO, 1990). AASHTO (AASHTO 1990) assumes a value of 2.5 second brake reaction time for stopping sight distance. Since decision sight distance for a lance change is *substantially greater*, a value of 5 second was considered for perception-reaction time during lane change (for passing maneuver son two-lane highways, AASHTO (AASHTO, 1990) assumes a reaction time of 3.6 to 4.5 seconds depending on speeds. For path changing on rural highways, the median value of decision sight distances for the range of speeds suggested by AASHOT (AASHTO 1990) corresponds to a reaction time of approximately 4 seconds. Though these maneuvers are different from the maneuve for passing postulated in this model, the values indicate that the reaction time is higher than that of 2.5 seconds for stopping).

Therefore, using the values of stopping sight distances as suggested by ASHTO (AASHTO 1990) and a perception-reaction time of 5 seconds, the critical gaps (T_B) for different roadway operating speeds are as follow.

Extent of Impact (EI)

The extent of impact (EI) may be defined as the total number of following vehicles that may be affected (i.e., experience a speed reduction) due to a left turning vehicle. this is the sum of the immediately following vehicle and the vehicles upstream that were forced to execute speed-change cycles due to the turning of the lead vehicle. The EIs for different combinations of traffic volume, roadway speed, and turning speed were calculated by simulating vehicular movements prior to an unsignalized intersection (Hasan 1998). The results of the simulation were used to formulate the following equations.

$$(EI)_{2L} = -1.75+0.0045V-0.000072U\frac{3}{T} + 0.000348U^2 \qquad (R^2 = 0.84) \qquad (viii)$$

$$(EI)_{4L} = -3.65+0.000001813\,V^2-0.000072U\frac{3}{T}+0.06382U \quad (R^2 = 0.95) \qquad (ix)$$

where,	$(EI)_{2L}$	=	Extent of impact per left-turn on two-lane highways
	$(EFV)_{4L}$	=	Extent of impact per left-turn on four-lane highways
	V	=	Approach traffic volume, V_{ph}
	U	=	Roadway operating speed, *kmph*
	U_T	=	Left-turn speed, *kmph*

It is to be noted that, by definition, the minimum value of EI is one (indicating the situation when only the immediately following vehicle is impacted). Also, hen equations (viii) and (ix) give a negative value, the EI is zero, indicating that left turns do not cause any impact on the immediately following vehicle.

The EI values calculate for different combinations of traffic volume, roadway operating speed, and turning speed are given in Tables 3 and 4. As expected, the EI increases with increase in traffic volume as well as with increase in roadway operating speed. On the other hand, EI decreases with increase in turning speed traffic volume, since increased turning speed results in less decelerating time of the turning vehicle on the roadway.

Table 1. Critical headway (T_A) for different roadway operating speeds.

Roadway Operating Speed (*kmph*)	Critical Headway, T_A (*sec*)
60	11.73
70	14.50
80	17.28
90	20.06
100	22.84

Table 2. Critical Gap, T_B for different roadway operating speeds.

Roadway Operating Speed (*kmph*)	Critical Gap, T_B (*sec*)
60	15.97
70	17.55
80	18.03
90	18.42
100	19.27

MODEL VALIDATION

The basic model described in the preceding sections can be used to calculate the number of following vehicles impacted per hour due to left-turns. Using equations (i) through (ix), traffic conflicts per hour due to left-turns were calculated for the study intersections (Hasan 1998). Traffic conflict data also were also collected at the Kansas study intersections see Table 5). Indications of brake-lights of through vehicles following a lead left turning vehicle were observed noted as left-turn, same direction, rear-end conflicts (Cottrell 1981).

Statistical tests were performed to determine the predictive power of the model. Tests show that there is a high correlation between the observed conflicts in field and their corresponding predicted values ($r = 0.96$). The regression of observed conflicts on predicted conflicts show that the coefficient of predicted conflicts is 0.83 and this value is significantly different from zero ($p < 0.0001$). However, the intercept is not significantly different from zero. the t-test was carried out to test the null hypothesis, H_0: $\beta = 1$ against the alternate hypothesis, H_a : $\beta \neq 1$. Results showed that the coefficient of predicted conflicts (β) was not significantly different from 1 at 10 percent level of significance. Therefore, it can be concluded that the model developed in this study performs reasonably well in predicting the number of conflicts that can be caused by left-turns.

Table 3. Extent of Impact (EI) for various combinations of roadway operating speeds, left-turn speeds, and approach volumes on 2-lane highways.

Approach Volume (vph)	Roadway Operating Speed (km/h)				
	60	70	80	90	100
	Left-turn Speed = 15 km/h				
100	0	0	1	1	2
200	0	1	1	2	2
300	1	1	2	2	3
400	1	2	2	3	3
500	2	2	2	3	4
600	2	2	3	4	4
700	2	3	3	4	5
800	3	3	4	4	5
900	3	4	4	5	6
1000	4	4	5	5	6
Approach Volume (vph)	Roadway Operating Speed (km/h)				
	60	70	80	90	100
	Left-turn Speed = 20 km/h				
100	0	0	0	1	2
200	0	0	1	1	2
300	0	1	1	2	3
400	1	1	2	2	3
500	1	2	2	3	3
600	2.	2	3	3	4
700	2	3	3	4	4
800	3	3	4	4	5
900	3	3	4	5	5
1000	3	4	4	5	6
Approach Volume (vph)	Roadway Operating Speed (km/h)				
	60	70	80	90	100
	Left-turn Speed = 25 km/h				
100	0	0	0	0	1
200	0	0	0	1	2
300	0	0	1	1	2
400	0	1	1	2	2
500	1	1	2	2	3
600	1	2	2	3	3
700	2	2	3	3	4
800	2	2	3	4	4
900	2	3	3	4	5
1000	3	3	4	4	5

Table 4. Extent of Impact (EI) for various combinations of roadway operating speeds, left-turn speeds, and approach volumes on 4-lane highways.

Approach Volume (vph)	Roadway Operating Speed (km/h)				
	60	70	80	90	100
	Left-turn Speed = 15 km/h				
200	0	1	1	2	3
400	0	1	2	2	3
600	1	1	2	3	3
800	1	2	2	3	4
1000	2	2	3	4	4
1200	3	3	4	4	5
1300	3	4	4	5	6
1400	3	4	5	5	6
1500	4	5	5	6	7
1600	5	5	6	6	7

Approach Volume (vph)	Roadway Operating Speed (km/h)				
	60	70	80	90	100
	Left-turn Speed = 20 km/h				
200	0	0	1	2	2
400	0	1	1	2	2
600	0	1	2	2	2
800	1	1	2	3	3
1000	1	2	3	3	4
1200	2	3	3	4	5
1300	3	3	4	5	5
1400	3	4	4	5	6
1500	4	4	5	6	6
1600	4	5	6	6	7

Approach Volume (vph)	Roadway Operating Speed (km/h)				
	60	70	80	90	100
	Left-turn Speed = 25 km/h				
200	0	0	0	1	2
400	0	0	1	1	2
600	0	0	1	2	2
800	0	1	1	2	3
1000	1	2	2	3	3
1200	2	2	3	4	4
1300	2	3	3	4	5
1400	3	3	4	5	5
1500	3	4	4	5	6
1600	4	4	5	6	6

Table 5. Comparison of rear-end conflicts at Kansas study intersections.

Study intersection	Conflict observed in the field	Conflict predicted by model (equation vii)
I1	1	0
I2	79	88
I3	4	0
I4	3	0
I5	37	31
I6	32	52
I7	40	33
I8	1	1

CONCLUSIONS

The model developed in this study can be applied to calculate the hourly rear-end conflicts that can be caused by left-turns on two-lane and four-lane rural highways. Statistical tests showed that the model performs reasonably well in predicting the traffic conflicts experienced by the following through vehicles due to left-turn maneuvers.

The equations developed for EI showed that both traffic volume (V) and speed (U) have positive coefficients while the coefficient for turning speed (U_T) is negative. Therefore, the equations for EI are logical and conceptually sound because EI should increase with speed and traffic volume for a given turning speed. Likewise, EI should decrease with increasing turning speed for given volume traffic and roadway operating speed.

The variables like traffic volume, turning traffic volume, roadway operating speed, and turning speed required to estimate the conflicts can be obtained from the field easily. Apart from its applicability in developing guidelines for treating left-turn traffic at unsignalized intersections on rural highways, this model also can be used to identify the locations with high probability of rear-end accidents.

REFERENCES:

American Association of State Highway and Transportation Officials, AASHTO (1990), a Policy on Geometric Design of Highways and Streets. Washington, D.C.

Cottrell, B.H. (1981), "The Development of criteria for the Treatment of Right Turn Movements on Rural Roads". Final Report: VHTRC 8-R45. Virginia Highway and Transportation Research Council, Charlottesville, Virginia.

Drew, D.R. (1968), Traffic Flow Theory and Control, McGraw-Hill Book Company, New York.

Hasan, T. (1998), "Development of Warrants for Right-Turn Treatments at Unsignilized Intersections, Ph.D. Dissertation, Department of Civil Engineering, Kansas state University, Manhattan, K.S.

Hasan, T. and Stokes, R.W. (1996), "Guidelines for Right-Turn Treatments at unsignalized Intersections and Driveways", Final Report: K-TRAN Project Number KSU-95-5, Kansas State University, Manhattan, K.S.

Mounce, J.M. (1993), "Influence of Arterial Access Control on Driveway Design and Energy Consumption", Transportation Research Record 901, Transportation Research Board, Washington, D.C.