Accident Exposure and Intersection Safety for At-Grade, Unsignalized Intersections

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The purpose of this study is to provide a method that will enable traffic and safety engineers to compare certain types of intersections relative to traffic safety. The method is based on determining an accident exposure index and could be utilized to identify the intersections that are prone to accidents. Four priority-type, unsignalized, at-grade intersections of varying geometrics were investigated. A fairly good correlation was found between the number of accidents and the accident exposure index. The index was calculated on the basis of the merging of the two traffic streams, and hence the single-vehicle accidents cannot be assumed to correlate with the index.

•BECAUSE urban transportation systems are planned with emphasis on auto travel, it becomes increasingly important to ensure the optimum operation of the system. However, as a chain is only as strong as its weakest link, so the overall operation of a highway system is highly dependent on the operations in critical sections. Intersections in a street system and interchanges in a freeway system can be regarded as the weak links. One very important component of the system is the at-grade intersection. It is important that the traffic engineer know which control is best for a given intersection condition. However, only meager information is available concerning controls below the level of traffic signals.

The purpose of this study is to enable traffic and safety engineers to compare certain types of unsignalized intersections relative to traffic safety. This method is based on determining an accident exposure index for selected intersections to identify those that are prone to accidents, especially during the daylight hours. The intersections investigated in this study are the priority type—the type of intersection where one of the intersecting streets is given a definite priority over other streets. The nonpriority or minor street for such an intersection is controlled by either a "stop" or "yield" sign. In this study, all minor street approaches are controlled by a "stop" sign.

Each driver would like to proceed as he pleases through a street network from his origin to his destination. Because his path crosses that of other vehicles at intersections in the system, however, it is desirable to minimize the chances that the potential intersection of vehicle paths will result in collisions.

STUDY SITES AND DATA COLLECTION PROCEDURE

Site Selection

After consultations with personnel of the Safety Section of the District of Columbia Department of Highways and Traffic, four intersections were selected for investigation. They were the intersections of 7th Street and Michigan Avenue N.E. (Fig. 1), 11th and P Streets N.W. (Fig. 2), 9th and K Streets N.W. (Fig. 3), and 12th and C Streets N.E.

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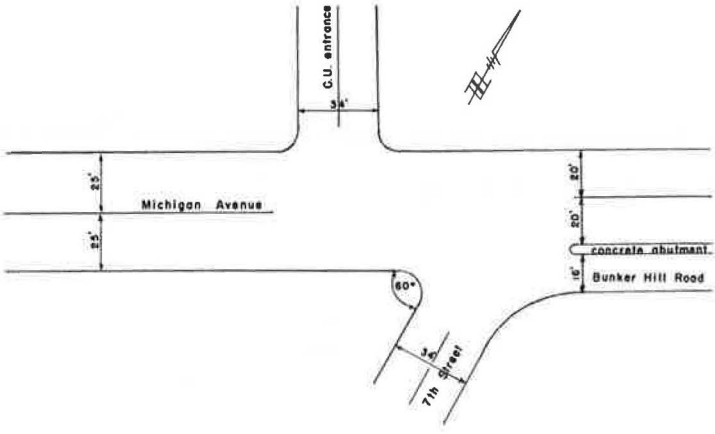

Figure 1. Intersection of 7th Street and Michigan Avenue N.E.

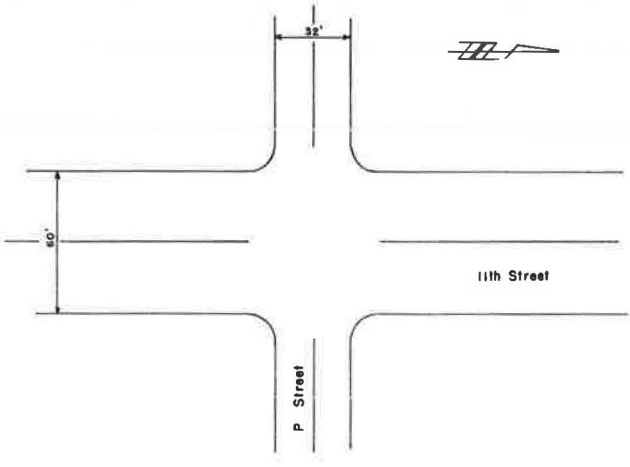

Figure 2. Intersection of 11th and P Streets N.W.

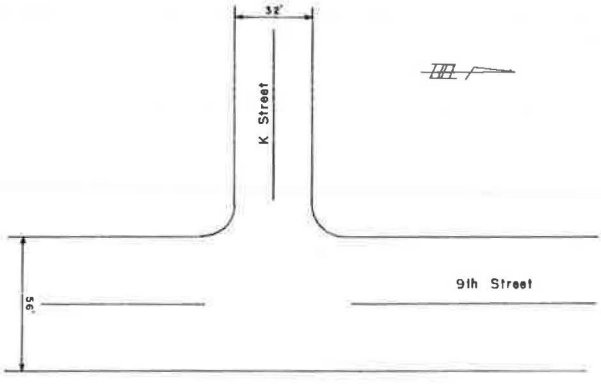

Figure 3. Intersection of 9th and K Streets N.W.

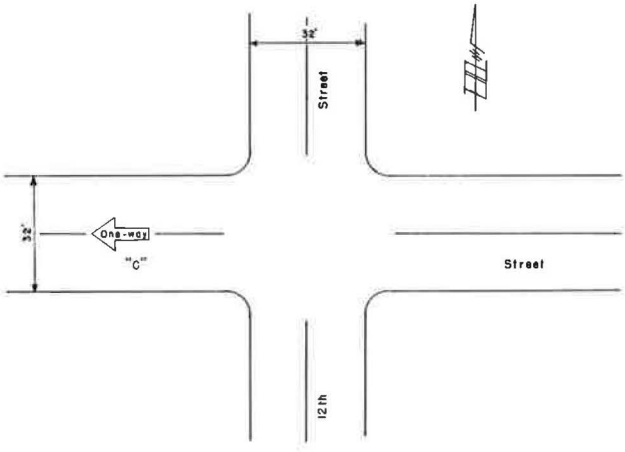

Figure 4. Intersection of 12th and C Streets N.E.

(Fig. 4). All were unsignalized, at-grade, priority-type intersections. A brief description of each intersection location is given in Table 1.

Data Collection for Peak-Hour Demand

One-hour traffic counts on a 5-minute basis were obtained for all approaches on each intersection study site during the afternoon peak period. Three recorders were found to be adequate for this purpose. Traffic counts for each approach were stratified into left turn, through, and right turn maneuvers.

SAFETY ANALYSIS

A collision between two moving vehicles can occur only when both vehicles attempt to occupy the same space at the same time. Thus, highway accidents can occur only under four conditions: head-on collision, rear-end collision, sideswiping, and crossing each other's travel path. Highway design can minimize or entirely eliminate all of the conditions under which such accidents occur. The degree of traffic congestion and the degree of hazard are determinant design factors, subject to considerations of construction and right-of-way cost, physical topography, and developments.

This investigation is primarily concerned with the identification of "accident prone" at-grade, unsignalized, priority-type intersections.

The term "accident prone", which has received wide use, has acquired many different definitions. Some traffic engineers prefer an absolute number of accidents occurring at a given location per year as a criterion, whereas others take into account traffic volumes with the resulting use of an index value such as accidents per million vehicles

TABLE 1

SUMMARY OF STUDY INTERSECTIONS

Intersection	Type	Major Street	Minor Street	Location Within Metropolitan Area
7th Street and Michigan Avenue N.E.	4-legged, two-way with two-way	Michigan Avenue	7th Street	Outlying business district
11th and P Streets N.W.	4-legged, two-way with two-way	11th Street	P Street	Outlying business district
9th and K Streets N.W.	T-type, two-way with two-way	9th Street	K Street	Fringe area
12th and C Streets N.E.	4-legged, C Street one-way, 12th Street two-way	C Street	12th Street	Outlying business district

per year at intersections or accidents per hundred million vehicle-miles per year on sections of open highway. There is a need for a standard criterion for an accident prone location and, perhaps more important, a method by which it can be determined.

Accident Exposure Index for a Four-Legged, At-Grade Intersection

In studying traffic movements at highway intersections, the conventional method of portraying the direction and density of vehicle traffic is by means of vectors in which an arrow indicates the direction of the flow and a variable bandwidth indicates the traffic density. The maximum number of traffic vectors at an intersection is equal to the product of the number of legs entering the intersection, n, times the same number minus one, n - 1; that is, n(n - 1). For example, a four-legged, unsignalized, at-grade intersection has 12 directional arrows and 24 potential collision points where two vehicles have a probability of colliding (Fig. 5). The term "potential collision point" is defined as the point of intersection of two different vehicle travel paths. A vehicle going from west to east has the possibility of colliding with any vehicle that is traveling through any of the potential collision points in its path during the time interval that this vehicle passes each of these points. During this critical time interval, this vehicle has the possibility of colliding with as many vehicles as cross potential collision points 1, 12, 11, 10, 19, and 20. The accident exposure for a car going from north to west will be equal to the number of vehicles passing potential collision point 24 during the same time interval. For several vehicles going from north to west, the accident exposure would equal the sum of the products of the number of cars going from north to west and the number of cars passing potential collision point 24 for a given time interval.

Earlier, Surti (1) developed a procedure to determine an exposure index using average daily traffic (ADT) volumes. Because the distribution of the traffic volumes for an

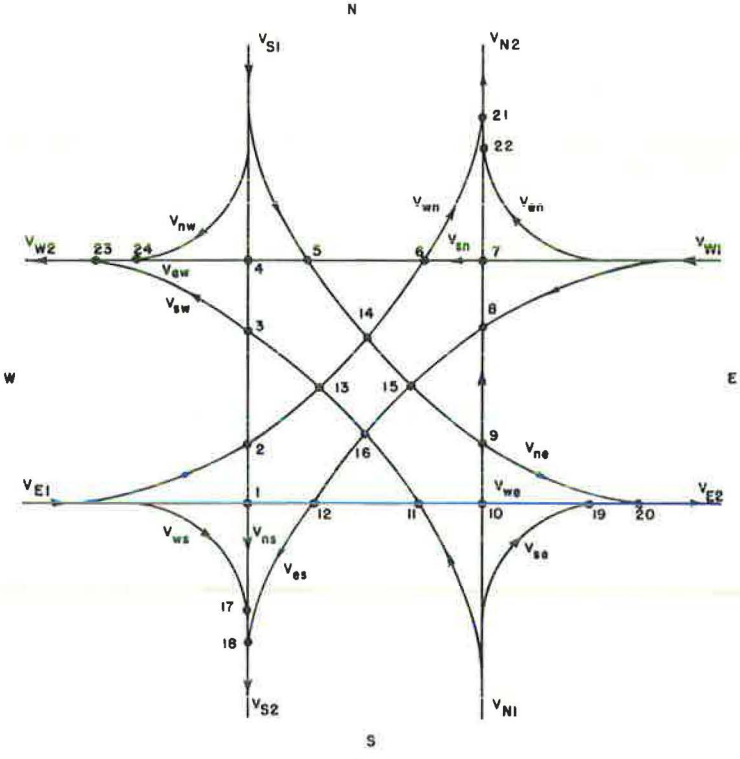

Figure 5. Potential collision points and directional maneuvers at a four-legged, unsignalized, at-grade intersection.

entire day is not uniform and more than half of the total trips are made during the peak periods, it would be more appropriate to use peak-hour volume to obtain the value for exposure index for a given intersection. Peak periods vary with the size of a city and the location of an intersection. For large metropolitan areas, the peak periods are generally considered from 7:00 to 9:30 a.m. for the inbound morning rush period and 4:00 to 6:30 p.m. for the outbound traffic. In this study, a method is developed for the determination of an accident exposure index for the priority-type, unsignalized, at-grade intersections, and an attempt is made to determine if there is any correlation between the accident exposure index and the number of accidents during the peak period.

In Figure 5, the peak-hour volumes (PHV) are shown as V_{ij}. The first character of the subscript represents initial direction and the second character represents final direction. The points at which the diverging maneuvers occur are not considered as potential collision points. First the exposure index for each of the potential collision points and then a general equation for the exposure index of the entire intersection are determined.

Exposure E_i at point 1 for a vehicle traveling from west to east for a given time interval i equals the number of vehicles southbound from the north direction during the same time interval i.

The exposure E_p for the entire peak period can be expressed as

$$E_p = \frac{PHV_{ns}\ (i)}{18{,}000}$$

where 18,000 is the number of seconds in one peak period (5 hours).

From this it follows that for the entire year

$$E_a = \frac{PHV_{ns}\ (i)\ 260}{18{,}000}$$

where 260 is the number of weekdays during 1 year.

The selection of the critical time period, i, could be arbitrary because it has only a relative value. To simplify calculations, about three-fourths of a second is assumed as a critical time. Substituting for i = 0.6923 second in the above expression, a simplified expression of the following form is obtained:

$$I = \frac{1}{100}\ PHV_{ns}$$

where I is the accident exposure index for each car traveling from west to east at potential collision point 1.

The total accident exposure index at the potential collision point 1 would be equal to

$$I_1 = \frac{1}{100}\ (PHV_{ns} \times PHV_{we})$$

or

$$100\ I_1 = PHV_{ns} \times PHV_{we}$$

It is assumed that the flows of traffic in the opposite directions are equal and there is a balanced traffic movement. At first this assumption seems unreasonable because there is unbalanced directional traffic volume during the morning and afternoon peak periods. However, when we consider the total time of the morning and afternoon peak periods, the total traffic in each direction is generally balanced out.

Let V_{E1}, V_{W1}, V_{N1}, and V_{S1} be the respective eastbound, westbound, northbound, and southbound peak-hour traffic volumes before crossing the intersection. Also let

V_{E2}, V_{W2}, V_{N2}, and V_{S2} be the respective eastbound, westbound, northbound, and southbound peak-hour traffic volumes after crossing the intersection. The peak-hour volume V_{E1} consists of vehicles on the eastbound approach leg that intend to make either through, left, or right turn movements. We can write this in the form of an equality expression. Thus we have the following expressions for V_{E1}, V_{W1}, V_{N1}, and V_{S1}:

Before crossing the intersection

$$V_{E1} = V_{wn} + V_{we} + V_{ws}$$

$$V_{W1} = V_{en} + V_{ew} + V_{es}$$

$$V_{N1} = V_{se} + V_{sn} + V_{sw}$$

$$V_{S1} = V_{nw} + V_{ne} + V_{ns}$$

The peak-hour traffic volume V_{E2} is made up of traffic approaching from north, west, and south after they have crossed the intersection. We can write the equality expressions for V_{E2}, V_{W2}, V_{N2}, and V_{S2} in a manner similar to the expressions for before crossing the intersection:

After crossing the intersection

$$V_{E2} = V_{ne} + V_{we} + V_{se}$$

$$V_{W2} = V_{nw} + V_{ew} + V_{sw}$$

$$V_{N2} = V_{en} + V_{wn} + V_{sn}$$

$$V_{S2} = V_{es} + V_{ws} + V_{ns}$$

Because we have assumed a balanced traffic movement and equal traffic volumes in the opposite directions, we have

$$V_{E1} = V_{W2}$$

$$V_{E2} = V_{W1}$$

$$V_{S1} = V_{N2}$$

$$V_{S2} = V_{N1}$$

and

$$V_{ns} = V_{sn} = a$$
$$V_{ew} = V_{we} = b$$
$$V_{es} = V_{se} = c$$

$$V_{wn} = V_{nw} = d$$
$$V_{sw} = V_{ws} = e$$
$$V_{ne} = V_{en} = f$$

The values of 100 times the accident exposure index of each of the 24 potential collision points are given in Table 2.

The exposure index for the entire intersection would equal the sum of the indexes of each of the 24 collision points:

$$\begin{aligned} 100\ I_T &= ab + ad + ae + ab + bf + bd + ab + ac + af + ab + be + bc + de + df \\ &\quad + cf + ce + ae + ac + bc + bf + ad + af + be + db \\ &= 4\ ab + 2\ ad + 2\ ae + 2\ bf + 2\ bd + 2\ ac + 2\ af + 2\ be + 2\ bc + de \\ &\quad + df + ce + cf \end{aligned}$$

Rearranging and adding and subtracting 2 ab in the above expression gives

$$\begin{aligned} 100\ I_T &= 2\ ab + 2\ ad + 2\ ae + 2\ ab + bf + 2\ bd + 2\ ab + 2\ ac + 2\ af - 2\ ab \\ &\quad + 2\ be + 2\ bc + de + df + ce + cf \\ &= 2\ a\ (b + d + 3) + 2\ b\ (a + f + d) + 2\ a\ (b + c + f) + 2\ b(c + e - a) \\ &\quad + (c + d)\ (e + f) \end{aligned}$$

Adding and subtracting 2 a to the fourth term in parentheses and by substitution gives

$$\begin{aligned} 100\ I_T &= 2\ a\ (V_{E1}) + 2\ b\ (V_{S1}) + 2\ a\ (V_{W1}) + 2\ b\ (c + e + a - 2\ a) \\ &\quad + (V_{es} + V_{wn})(V_{sw} + V_{ne}) \\ &= 2\ a\ (V_{E1} + V_{W1}) + 2\ b\ (V_{N1} + V_{S1} - 2\ V_{ns}) + (V_{es} + V_{wn})(V_{sw} + V_{ne}) \end{aligned}$$

$$100\ I_T = 2\ V_{ns}\ (V_{E1} + V_{ns}) + 2\ V_{ew}\ (V_{N1} + V_{S1} - 2\ V_{ns}) + (V_{es} + V_{wn})(V_{sw} + V_{ne})$$

In the above equation the appropriate volumes in the opposite direction could be used (e.g., $V_{ns} = V_{sn}$, $V_{ne} = V_{en}$).

TABLE 2

ACCIDENT EXPOSURE INDEX OF EACH OF THE 24 POTENTIAL COLLISION POINTS FOR A FOUR-LEGGED, AT-GRADE INTERSECTION

Potential Collision Point Number	100 I	100 I for Balanced Movement	Potential Collision Point Number	100 I	100 I for Balanced Movement
1	$V_{we} \times V_{ns}$	a × b	13	$V_{wn} \times V_{sw}$	d × e
2	$V_{wn} \times V_{ns}$	d × a	14	$V_{ne} \times V_{wn}$	f × d
3	$V_{sw} \times V_{ns}$	e × a	15	$V_{es} \times V_{ne}$	c × f
4	$V_{ew} \times V_{ns}$	b × a	16	$V_{es} \times V_{sw}$	c × e
5	$V_{ew} \times V_{ne}$	b × f	17	$V_{ns} \times V_{ws}$	a × e
6	$V_{wn} \times V_{ew}$	b × b	18	$V_{ns} \times V_{es}$	a × c
7	$V_{ew} \times V_{sn}$	b × a	19	$V_{we} \times V_{se}$	b × c
8	$V_{sn} \times V_{es}$	a × c	20	$V_{we} \times V_{ne}$	b × f
9	$V_{sn} \times V_{ne}$	a × f	21	$V_{sn} \times V_{wn}$	a × d
10	$V_{sn} \times V_{we}$	a × b	22	$V_{sn} \times V_{en}$	a × f
11	$V_{we} \times V_{sw}$	b × e	23	$V_{ew} \times V_{sw}$	b × e
12	$V_{we} \times V_{es}$	b × c	24	$V_{ew} \times V_{nw}$	b × d

TABLE 3

PEAK-HOUR APPROACH AND DIRECTIONAL TRAFFIC VOLUMES FOR THE 7TH STREET AND MICHIGAN AVENUE N.E. INTERSECTION

Approach Volume	Directional Volume
$V_{E1} = 965$	$V_{ns} = 19$
$V_{W1} = 485$	$V_{ew} = 400$
$V_{N1} = 179$	$V_{es} = 50$
$V_{S1} = 101$	$V_{wn} = 8$
	$V_{sw} = 6$
	$V_{ne} = 62$

TABLE 4

PEAK-HOUR APPROACH AND DIRECTIONAL TRAFFIC VOLUMES FOR THE 11TH AND P STREETS N.W. INTERSECTION

Approach Volume	Directional Volume
$V_{E1} = 126$	$V_{ns} = 489$
$V_{W1} = 131$	$V_{ew} = 74$
$V_{N1} = 800$	$V_{es} = 14$
$V_{S1} = 539$	$V_{wn} = 2$
	$V_{sw} = 36$
	$V_{ne} = 40$

Research in this field has been undertaken by May (2), Grossman (3), and Breuning and Bone (4). May presented a statistical method of determining an accident prone location by comparing accident rates with the traffic volumes for a series of intersections. Using this information, he computed a regression line. The accident rates are defined as accident rates per million vehicles per year at intersections. An accident prone location can be assumed to exist if its rate is greater than one standard deviation above the regression line.

Grossman developed a numerical index for the accident exposure index. He employed 24-hour traffic counts and used the sums of the crossing movements.

Breuning and Bone also used average daily traffic volumes and developed a procedure for determining the accident exposure index for freeway interchanges. This index is a dimensionless quantity, and has a built-in weighted effect for all directional maneuvers. It not only can identify the intersections that are accident prone, but also can prove useful in comparison of intersections before and after improvements. A similar approach can be used to determine exposure indexes for T-type, one-way with one-way, one-way with two-way, and other types of intersections.

Index for 7th Street and Michigan Avenue Intersection—Michigan Avenue and 7th Street N.E. form essentially a four-legged intersection, because the traffic generated by the Bunker Hill Road approach is insignificant compared to the remaining four approaches. The peak-hour volume for Bunker Hill Road was less than 10 vehicles and hence it can be ignored. We can use the formula developed for the four-legged intersection to determine the peak-period accident exposure index value for this intersection. Table 3 gives the necessary peak-hour traffic volumes.

The accident exposure index expression for a four-legged intersection as developed earlier is as follows:

$$100\, I_T = 2\, V_{ns}\, (V_{E1} + V_{W1}) + 2\, V_{ew}\, (V_{N1} + V_{S1} - V_{ns}) + (V_{es} + V_{wn})(V_{sw} + V_{ne})$$

By substitution of the appropriate values from Table 3, we have

$$100\, I_T = 2\,(19)(965 + 485) + 2\,(400)\ [179 + 101 - (2 \times 19)] + (50 + 8)(6 + 42)$$

$$100\, I_T = 38\,(1450) + 800\,(280 - 38) + (58)(68)$$

$$100\, I_T = 55{,}100 + 193{,}600 + 3{,}944$$

$$I_T = \frac{252{,}644}{100}$$

$$I_T = 2526.44$$

The peak-period accident exposure index for 7th Street and Michigan Avenue N.E. is thus 2526.44.

Index for 11th and P Streets Intersection—The intersection of 11th and P Streets N.W. also falls in the category of a four-legged intersection and we can make use of the same expression to determine the peak-period accident exposure index. The traffic volumes necessary to compute the peak-period accident exposure index are given in Table 4. Again using the expression for the peak-period accident exposure index we have

$$100\ I_T = 2\ V_{ns}\ (V_{E1} + V_{W1}) + 2\ V_{ew}\ (V_{N1} + V_{S1} - 2\ V_{ns}) + (V_{es} + V_{wn})(V_{sw} + V_{ne})$$

Substituting the appropriate traffic volumes from Table 4, we have

$$100\ I_T = 2\ (489)(126 + 131) + 2\,(74)\ [800 + 539 - 2\ (489)] + (14 + 2)(36 + 40)$$

$$100\ I_T = 2\ (489)(257) + 2\ (74)(361) + 16\ (76)$$

$$100\ I_T = 251{,}346 + 53{,}428 + 1{,}216$$

$$100\ I_T = 305{,}990$$

$$I_T = 3059.90$$

The peak period accident exposure index for the 11th and P Streets N.W. intersection is thus 3059.90.

Accident Exposure Index for a T-Type, Unsignalized, At-Grade Intersection

The potential collision points and directional maneuvers for a typical "T" intersection are shown in Figure 6. It has six potential collision points and six directional

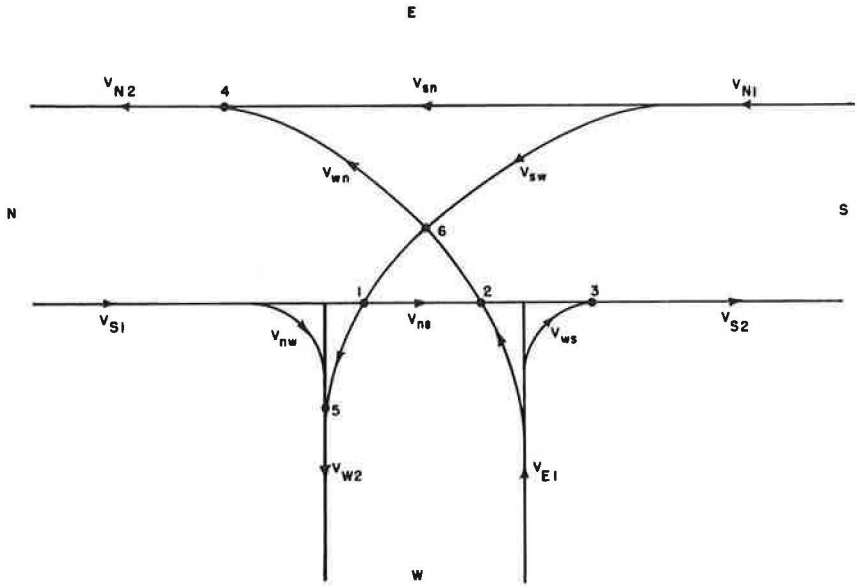

Figure 6. Potential collision points and directional maneuvers at a T-type, unsignalized, at-grade intersection.

maneuvers. Again we use the same terminology developed in the determination of peak-period accident exposure index for the four-legged intersection. The directional peak-hour traffic volumes are V_{ns}, V_{sn}, V_{nw}, V_{ws}, V_{sw}, and V_{wn}. Peak-hour approach traffic volumes before crossing the intersection are V_{E1}, V_{N1}, and V_{S1}; after crossing the intersection are V_{S2}, V_{N2}, and V_{W2}.

The total peak-period accident exposure index at potential collision point 1 is

TABLE 5

PEAK-PERIOD ACCIDENT EXPOSURE INDEX OF EACH OF THE SIX POTENTIAL COLLISION POINTS FOR A T-TYPE, UNSIGNALIZED, AT-GRADE INTERSECTION

Potential Collision Point Number	100 I	100 I for Balanced Movement
1	$V_{sw} \times V_{ns}$	a × b
2	$V_{ns} \times V_{wn}$	b × c
3	$V_{ws} \times V_{ns}$	a × b
4	$V_{sn} \times V_{wn}$	b × c
5	$V_{sw} \times V_{nw}$	a × c
6	$V_{sw} \times V_{wn}$	a × c

$$I_1 = \frac{1}{100} (V_{ns} \times V_{sw})$$

or

$$100\ I_1 = V_{ns} \times V_{sw}$$

Again assuming equal traffic flows in opposite directions and balanced traffic movement, we have $V_{E1} = V_{W2}$, $V_{S1} = V_{N2}$, $V_{N1} = V_{S2}$, $V_{sw} = V_{ws}$, $V_{ns} = V_{sn}$, and $V_{wn} = V_{nw}$. The expression for peak-hour approach traffic volumes are as follows:

Before crossing the intersection

$$V_{E1} = V_{ws} + V_{wn}$$

$$V_{S1} = V_{nw} + V_{ns}$$

$$V_{N1} = V_{sw} + V_{sn}$$

After crossing the intersection

$$V_{N2} = V_{sn} + V_{wn}$$

$$V_{W2} = V_{nw} + V_{sw}$$

$$V_{S2} = V_{ws} + V_{ns}$$

Let $V_{sw} = V_{ws} = a$; $V_{ns} = V_{sn} = b$; and $V_{wn} = V_{nw} = c$.

The peak-period accident exposure index for the entire intersection is equal to the sum of the indexes of each of the six potential collision points. The index for each of the six potential collision points is given in Table 5.

The total peak-period accident exposure index for the intersection can now be written as

$$\begin{aligned} 100\ I_T &= ab + bc + ab + bc + ac + ac \\ &= 2\ ab + 2\ bc + 2\ ac \\ &= 2\ a\ (b + c) + 2\ bc \\ &= 2\ a\ (V_{S1}) + 2\ bc \\ 100\ I_T &= 2\ V_{ws}\ (V_{S1}) + 2\ V_{ns}\ V_{nw} \\ 50\ I_T &= V_{ws}\ V_{S1} + V_{ns}\ V_{nw} \end{aligned}$$

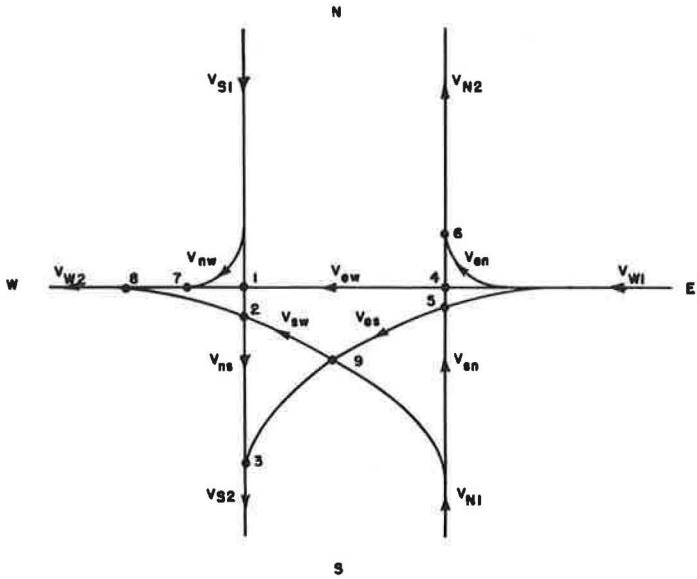

Figure 7. Potential collision points and directional maneuvers at a four-legged, one-way with two-way, unsignalized, at-grade intersection.

Index for 9th and K Streets Intersection—The intersection at 9th Street and K Street N.W. is a T-type, unsignalized, at-grade intersection and the expression just derived can be used to determine the peak-period accident exposure index:

$$50\ I_T = V_{ws}\ V_{S1} + V_{ns}\ V_{nw}$$

Utilizing the required peak-hour approach and directional traffic volumes from the data for this intersection, we have $V_{S1} = 970$, $V_{ws} = 255$, $V_{ns} = 710$, and $V_{nw} = 260$. By substitution in the expression, we have

$$\begin{aligned} 50\ I_T &= V_{ws}\ V_{S1} + V_{ns}\ V_{nw} \\ &= 255\,(970) + 710\,(260) \\ &= 247{,}350 + 184{,}600 \\ 50\ I_T &= 431{,}950 \\ I_T &= 8639.0 \end{aligned}$$

The peak-period accident exposure index for the 9th and K Streets intersection is thus 8639.0.

Accident Exposure Index for a Four-Legged, One-Way With Two-Way, Unsignalized, At-Grade Intersection

The potential collision points and directional maneuvers for a typical one-way with two-way intersection are shown in Figure 7. It has nine potential collision points and seven directional maneuvers. It is interesting to note that just by having one street one-way for a four-legged intersection, the number of potential collision points is reduced from 24 to 9.

The intersection shown in Figure 7 is one-way in the westbound direction and two-way in the north-south direction. The peak-hour directional traffic volumes are V_{ns},

V_{sn}, V_{ew}, V_{en}, V_{nw}, and V_{es}. Peak-hour approach traffic volumes before crossing the intersection are V_{W1}, V_{N1}, and V_{S1}; after crossing the intersection they are V_{W2}, V_{N2}, and V_{S2}.

The total peak-period accident exposure index for this intersection at potential collision point 1 is

$$I_1 = \frac{1}{100} (V_{ew} \times V_{ns})$$

or

$$100\ I_T = V_{ew} \times V_{ns}$$

TABLE 6

PEAK-PERIOD ACCIDENT EXPOSURE INDEX OF EACH OF THE NINE POTENTIAL COLLISION POINTS FOR A FOUR-LEGGED, ONE-WAY WITH TWO-WAY, UNSIGNALIZED, AT-GRADE INTERSECTION

Potential Collision Point Number	100 I	Potential Collision Point Number	100 I
1	$V_{ew} \times V_{ns}$	6	$V_{en} \times V_{sn}$
2	$V_{sw} \times V_{ns}$	7	$V_{nw} \times V_{ew}$
3	$V_{es} \times V_{ns}$	8	$V_{sw} \times V_{ew}$
4	$V_{ew} \times V_{sn}$	9	$V_{sw} \times V_{es}$
5	$V_{ew} \times V_{sn}$		

Assuming, as before, equal traffic flows in the opposite directions and balanced traffic movement, we have $V_{N1} = V_{S2}$, $V_{S1} = V_{N2}$, and $V_{sn} = V_{ns}$.

The expressions for peak-hour approach traffic volumes are as follows:

Before crossing the intersection

$$V_{N1} = V_{en} + V_{ew} + V_{es}$$
$$V_{N1} = V_{sn} + V_{sw}$$
$$V_{S1} = V_{nw} + V_{ns}$$

After crossing the intersection

$$V_{W2} = V_{nw} + V_{sw} + V_{ew}$$
$$V_{N2} = V_{en} + V_{sn}$$
$$V_{S2} = V_{es} + V_{ns}$$

The peak-period accident exposure index for each of the nine potential collision points is given in Table 6.

The total peak-period accident exposure index for the intersection is equal to the sum of the indexes of each of the nine potential collision points:

$$\begin{aligned} 100\ I_T = {} & (V_{ew}\ V_{ns}) + (V_{sw}\ V_{ns}) + (V_{es}\ V_{ns}) \\ & + (V_{ew}\ V_{sn}) + (V_{es}\ V_{sn}) + (V_{en}\ V_{sn}) \\ & + (V_{nw}\ V_{ew}) + (V_{sw}\ V_{ew}) + (V_{sw}\ V_{es}) \end{aligned}$$

Because we have assumed $V_{ns} = V_{sn}$

$$\begin{aligned} 100\ I_T = {} & V_{ns}\ (V_{ew} + V_{es} + V_{en}) + V_{ew}\ (V_{ns} + V_{nw}) + V_{ns}\ (V_{sw} + V_{es}) \\ & + V_{sw}\ (V_{ew} + V_{es}) \end{aligned}$$

$$100\ I_T = V_{ns}\ (V_{W1}) + V_{ew}\ (V_{N1}) + V_{ns}\ (V_{sw} + V_{es}) + V_{sw}\ (V_{ew} + V_{es})$$

TABLE 7

A SUMMARY OF ACCIDENTS AND PEAK-PERIOD ACCIDENT EXPOSURE INDEXES FOR THE SELECTED INTERSECTIONS

Intersection	Type of Intersection	Peak-Period Exposure Index	Number of Accidents, Daylight Hours, 1966-1967
7th Street and Michigan Avenue N.E.	Four-legged, two-way with two-way, minor street approaches offset by about 100 ft	2526.44	3
11th and P Streets N.W.	Four-legged, two-way with two-way	3059.90	10
9th and K Streets N.W.	T-type, all approaches two-way	8639.00	25
12th and C Streets N.E.	Four-legged, C Street one-way westbound, 12th Street two-way	1344.67	2

Index for 12th and C Streets Intersection—The intersection at 12th Street and C Street N.E. falls in the category of a four-legged, one-way with two-way, unsignalized, at-grade type of intersection. Using the expression for the peak-period accident exposure index just derived, we have

$$100\ I_T = V_{ns}\ (V_{W1}) + V_{ew}\ (V_{N1}) + V_{ns}\ (V_{sw} + V_{es}) + V_{sw}\ (V_{ew} + V_{es})$$

Using the peak-hour approach and directional volumes for this intersection, we have $V_{N1} = 85$, $V_{W1} = 810$, $V_{ns} = 69$, $V_{ew} = 739$, $V_{sw} = 18$, and $V_{es} = 14$. By substitution,

$$\begin{aligned} 100\ I_T &= 69\ (810) + 739(85) + 69\ (18 + 14) + 18\ (739 + 14) \\ &= 55{,}890 + 62{,}815 + 2{,}208 + 13{,}554 \\ &= 134{,}467 \\ I_T &= 1344.67 \end{aligned}$$

The peak-period accident exposure index for the 12th Street and C Street N.E. intersection is thus 1344.67.

EVALUATION

The accident information for the selected intersections was obtained from the files of the District of Columbia Department of Highways and Traffic. Only accidents during daylight hours (6:00 a.m. to 6:00 p.m.) for a 2-year period (1966-1967) on the selected intersections were considered.

Table 7 gives the accident information and the peak-period accident exposure index for the four selected intersections. It is observed that there is a fairly good correlation between the number of accidents during the daylight hours and the peak-period accident exposure index. Based on this exposure index, accident rates for intersections become easily comparable and allow a direct analysis of the safety of each intersection design.

It must be remembered, however, that the exposure index is calculated on the basis of accidents caused by the merging of the two traffic streams. Single-vehicle accidents cannot be assumed proportional to the product of the two traffic streams. There are also complications of driver behavior under various traffic and emotional circumstances. Accidents of this type certainly will not correlate with the exposure index.

The peak-period accident exposure index is only a relative value and is free of any units, similar to the Reynold's number in hydraulics, a measure of turbulence in the flow of a fluid. Similarly, the exposure index may be said to measure traffic friction at an intersection.

CONCLUSIONS

This investigation has shown that the peak-period accident exposure index is a reliable means of evaluating the "accident proneness" of an intersection. A fairly good correlation was found between the derived exposure index and the accident experience of the selected intersections during daylight hours.

REFERENCES

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4. Breuning, S. M., and Bone, A. J. Interchange Accident Exposure. HRB Bull. 240, p. 44-52, 1960.
5. Wohl, Martin, and Martin, Brian. Traffic System Analysis for Engineers and Planners. McGraw-Hill Book Co., New York, 1967.

Discussion

C. BLASE McCARTHY, Tulane University—While there is certainly a need for better techniques of measuring the accident potential or exposure of at-grade intersections, the supporting data in the subject paper do not appear to justify the conclusions that the proposed accident exposure index is a reliable means of evaluating the "accident proneness" of an intersection.

The suggested measure can be faulted on two major counts. One, the index is advanced as a measure of the total accident potential of an intersection without differentiating between classes of accidents or types of vehicle conflicts. Thus the proposed index does not seem to offer any significant advantage over existing techniques. A more useful index would be one that measures the hazard of various types of vehicle conflicts independently, such as the crossing conflict or the merging conflict. An index of this form would allow more detailed analysis of the intersection hazard and would allow remedial measures to be directed to the more dangerous maneuvers. For example, the elimination of left turns might reduce one type of conflict, but the corresponding increase in straight-through traffic might increase the total intersection accident potential if straight-through traffic is basically more hazardous than turning traffic.

Another objection to the format of the proposed index is with regard to the utilization of afternoon peak-hour traffic counts as a volume measure. The assumption that the morning peak-hour traffic balances the p.m. peak is absurd when applied to intersections containing one-way streets. Study Site No. 4, the intersection of 12th and C Streets N.E., is an example of this situation.

With regard to the data presented to substantiate the use of this exposure index, the following comments are in order.

At Site No. 1, the offset of 7th Street from the entrance to Catholic University created two additional conflict points between the left turn traffic from these cross streets.

At Site No. 2, 11th Street is 60 ft in width, which indicates two moving lanes in each direction. For multilane streets, it would seem reasonable to use lane volumes inasmuch as there are more potential conflict locations with smaller numbers of potential conflicts at each location. For example, a right turn from a minor street will merge only with the outside lane of the major street.

At Site No. 3, 9th Street is 56 ft in width and probably has four moving lanes.

A major objection to the study is that all four study sites are of distinctly different geometric characteristics. Personal studies of much larger samples of geometrically

similar intersections have shown wide variations in accident exposure even for similar traffic flows. The suggested correlation cannot be accepted in view of the exceedingly small sample size and variations in sample characteristics.

VASANT H. SURTI, Closure—Prof. McCarthy's discussion is quite beneficial to the clarification and usefulness of the method proposed by the author.

It is emphasized that the accident exposure index developed in the study is not meant to be a reliable means of evaluating the "accident proneness" of an intersection, but rather an initial step or approach toward finding a better accident determinant, because the simple fact is that accidents are often caused by the unpredictable driver.

The method proposed by McCarthy is hypothetical at this time, and the author would like to encourage him to conduct a research study.

The index is not intended to be a measure of the total accident potential of an intersection, but rather only of certain types of accidents (involving merging or turning movements) that can be directly attributable to a traffic control deficiency (e.g., the accident exposure index does not include single-vehicle, pedestrian, nighttime, and rear-end accidents).

With regard to the use of afternoon volume counts as a volume measure, the first Surti study ADT figures were used and the correlation between afternoon peak volumes and off-peak volumes was found to be acceptable. Because peak volumes represent the most critical conditions, they were used.

Time and funds permitted a sample of only four intersections; however, the results of research conducted by the New Jersey Department of Transportation (6) are worth noting. This study analyzed several intersections relative to safety using multiple regression and the accident exposure index techniques. The results were encouraging in favor of employing the accident exposure index technique as a relative measure of intersection safety.

Reference

6. Reilly, E. F. Intersection Design. New Jersey Department of Transportation. A paper presented at the 47th Annual Meeting of the Highway Research Board, January 1968.