Developing a Risk Assessment Rating for Conflict Points at Driveway Locations

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BACKGROUND AND PURPOSE

Access management along major facilities relies on effective driveway configurations and associated median or channelization treatments to achieve safe, smooth arterial operations and adequate service to adjacent land use activities. One common safety consideration at driveway locations is the number and type of conflict points. Conflict analysis has been used for many years to subjectively determine the safety or complexity of operations at a site.

The purpose of this paper is to develop and apply a risk assessment method to analyze and evaluate conflicts for a variety of driveway configurations. In addition to issues associated with the physical location and configuration, potential angle of impact, relative speed of conflicting vehicles, driver perception-reaction type, and type of potential crash, the volume of traffic then can be used to further assess the probability of crashes at a specific driveway location.

Since the purpose of this paper is the development of a risk assessment rating for driveways (a rating not currently available), the authors have elected to simplify this initial effort by primarily focusing on motor vehicle interactions; however, non-motorized operations such as bicycle and pedestrian should ultimately be included and are peripherally addressed in this paper.

DETERMINE LOCATION AND LAYOUT

To adequately assess the expected risks, a first step is to determine the spatial orientation and layout of the driveway configuration and associated conflict points. The location, orientation, and type of conflict should be defined as follows:

Location – develop a plan view of the location with key distances between conflict points;

Orientation – determine the relative orientation of the vehicle paths between conflict points in sufficient detail to determine the angles of impact of conflicting vehicles and to represent the nature of crashes that would occur at the location; and

Type of Conflict – establish descriptions for the various conflicts (i.e., crossing, merge, diverge, etc.).

DETERMINE THE INDIVIDUAL LEVEL OF CONFLICT VALUES

The level of conflict for a specific point is a factor of the orientation of the conflicting vehicles, their associated operation speeds, and the expected level of protection based on the frequency and type of conflict and impact angle. To provide relative risk assessments, this analysis uses an extreme (severe) crash condition as a comparison crash. This "base" crash is a head-on collision at speeds of 55 mph (88 km/hr) or greater [referred to as HO-55 in subsequent discussion]. All other levels of conflict will ultimately be adjusted to equivalent HO-55 crashes.

The level of conflict, LC, is a function of the relative speeds between conflicting vehicles and their angle of impact and conflict type. The LC can be extended to an effective level of conflict, ELC, which represents the increased likelihood of exposure due to other conflicts in close proximity. The following sections summarize how the LC and the ELC can be derived.

Relative Operating Speed

The kinetic or impact energy for a crash is a factor of the speed (or speed differences) and can be determined from the following well known relationship:

$$\text{Kinetic Energy} = \text{KE} = \frac{1}{2}\text{mS}^2$$

where m = mass of vehicle and S = speed.

For the HO-55 crash condition, this equation can be modified as follows:

$$KE_{HO\text{-}55} = \frac{1}{2}m(1.47\times55)^2 = 3254m$$

A speed adjustment factor, f_{spd}, can then be developed by contrasting the kinetic energy for the HO-55 to alternative relative speeds:

$$f_{spd} = \frac{KE_S}{KE_{HO-55}} = \frac{\frac{m}{2}(1.47\times S)^2}{3254m} = \frac{S^2}{3025}$$

where S = speed (mph).

If, for example, a vehicle travelling at 40 mph (64 km/hr) impacts another vehicle traveling in the same general direction at 30 mph (48 km/hr), the relative speed difference would be 10 mph (16 km/hr) and this relative speed would be directly associated with the resulting kinetic energy if the vehicles were involved in a crash. As a result, the relative speed for the crash can be used to determine the speed adjustment factor.

Conflict Orientation Factor

In a manner similar to procedures used for assigning costs to crashes, a severity factor based on crash type and vehicle orientation can be used to represent associated crash risk due to the conflict configuration. This conflict orientation factor, c, defines bicycle and pedestrian-involved crashes as extremely severe (c=1.0) followed by head-on crashes (c=0.8), right-angle crashes (c=0.6), sideswipe crashes (c=0.4), and rear-end crashes (c=0.3). The larger c value of 1.0 for the bicycle and pedestrian crashes is because these crashes are considered injury-related without regard to angle of impact.

Calculating the Level of Conflict

The value of the LC is based on a combination of the speed adjustment factor and the conflict orientation factor or LC = f_{spd} x c. To demonstrate this calculation consider Figure 1, Alternative I. For this sample configuration, a driveway intersects a road as a T-intersection. The road has a restrictive median so driveway movements are constrained to right-in right-out operations. This configuration can be contrasted to Alternative II where a median break provides full driveway access to and from both directions of travel. For Alternative I, the expected crash type at merge point "A" and diverge points "B" and "C" would be a rear-end crash (c=0.3). At merge point "D", however, rear-end as well as sideswipe crashes could be expected. Since the conflict orientation factor for a sideswipe crash is larger (c=0.4), it will be conservatively used for this analysis. Table 1 summarizes the type of conflict, speed, and summary calculations for Alternative I.

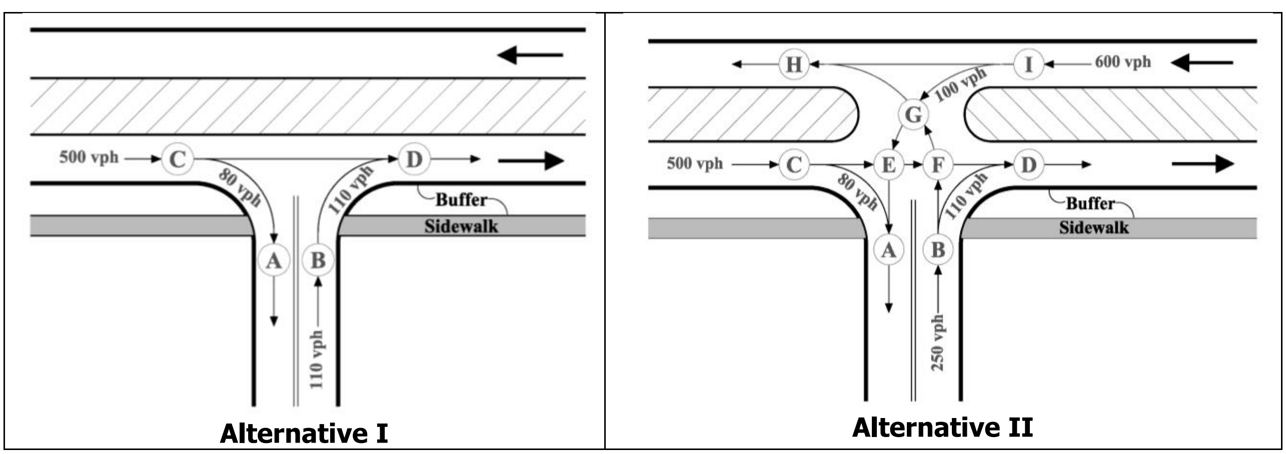


Figure 1. Alternative I and Alternative II Layouts and Volumes

Table 1. Alternative I Level of Conflict Calculations

Conflict Point	Type	Major Speed, S_{Major} (mph)	Minor Speed, S_{Minor} (mph)	Relative Speed, S (mph)	f_{spd}	c	LC	ELC
A	Merge	15	15	15	0.074	0.3	0.022	0.022
B	Diverge*	0	10	10*	0.033	0.3	0.010	0.010
C	Diverge*	50	15 (5**)	45*	0.669	0.3	0.201	0.401
D	Merge	50	10	40	0.529	0.4	0.212	0.212
							ELC_{INT}	0.646

*Use larger speed

**Speed vector for 15 mph exiting vehicle along arterial at point of exit is approximately 5 mph.

Nearness Index

The nearness index, NI, addresses how closely oriented conflicts can introduce additional risk. For example, if three conflicts all occur at the same point, they are treated as three full conflicts. As the conflict points are pulled apart, the level of conflict decreases.

A driver should ideally have sufficient time and distance to deal with one conflict before encountering a second conflict. If the distance between conflicts is less than the associated stopping sight distance, the second conflict point will increase the level of conflict for the initial conflict point. For the purposes of this analysis, the authors have employed the perception-reaction time and deceleration rates from the American Association of State Highway and Transportation Officials (AASHTO) document *A Policy on Geometric Design of Highways and Streets* (*1*) [referred to as the *Greenbook* from this point forward]. A perception-reaction time of 2.5 seconds is assumed for the initial conflict and 1.5 seconds for each additional conflict. This assumes that the stopping sight distance would be based on a perception-reaction time of 4.0 seconds for two conflict points. If the driveway is located along a busy urban arterial where the driver must remain on high alert, the perception-reaction time could be moderately reduced. The deceleration rate is assumed to be 11.2 ft/sec^2 (3.4 m/sec^2) as adopted by the *Greenbook*.

To assess the nearness effect of conflict points, the distance between the conflict points (d_{ab}) as well as the stopping sight distance (SSD) between the two points should be determined. Though the SSD can be reduced to reflect the speed of operation at the second conflict point (if it is not zero), a conservative value assumes the full SSD. At locations where the SSD_{ab} is less than d_{ab}, the authors recommend the use of a nearness index, NI. At locations where the SSD_{ab} is greater that d_{ab} , the NI is then zero. The NI is based on the negative exponential for the distance to conflict point to SSD ratio as follows:

$$\mathrm{NI} = \mathrm{e}^{-\frac{\mathrm{d_{ab}}}{\mathrm{SSD}}}$$

where d_{ab}=distance between conflict points a and b (ft or m) and SSD = stopping sight distance (ft or m). Using the SSD methods summarized in the *Greenbook* (*1*) and the conservative SSD value based on the highest conflicting speed, the authors developed a series of NI curves for the varying d_{ab} and SSD values as shown in Figure 2. Table 2 shows the distance and NI values for Alternative I.

Equivalent Level of Conflict

The total equivalent level of conflict, ELC, reflects the relative LC value for each conflict point combined with the influence of other closely spaced conflict points. As an example, the ELC_C for Alternative I can be determined as follows:

$$ELC_C = LC_C + LC_D\ (NI_{CD}) + LC_A\ (NI_{CA}) = 0.201 + (0.212)(0.87) + (0.022)(0.69) = 0.401$$

At locations that do not have downstream conflicts (such as merge Point D), $ELC_D = LC_D$. As a final step in the ELC evaluation, the individual ELC values for each conflict should be added together. As shown in Table 1, the ELC_{INT} = 0.646 or the sum of the individual ELC values for points A, B, C, and D. This ELC_{INT} value can be interpreted as an aggregate equivalent conflict measure of 0.646 HO-55 crashes for the driveway configuration presented in Alternative I. The ELC_{INT} value is based on vehicle interactions, relative speed, proximate conflict points, and impact angles. To fully assess risk, the traffic exposure must be considered. The following section reviews how the major and minor traffic volumes can be used to estimate the total number of conflicts and associated risk assessment at a known location.

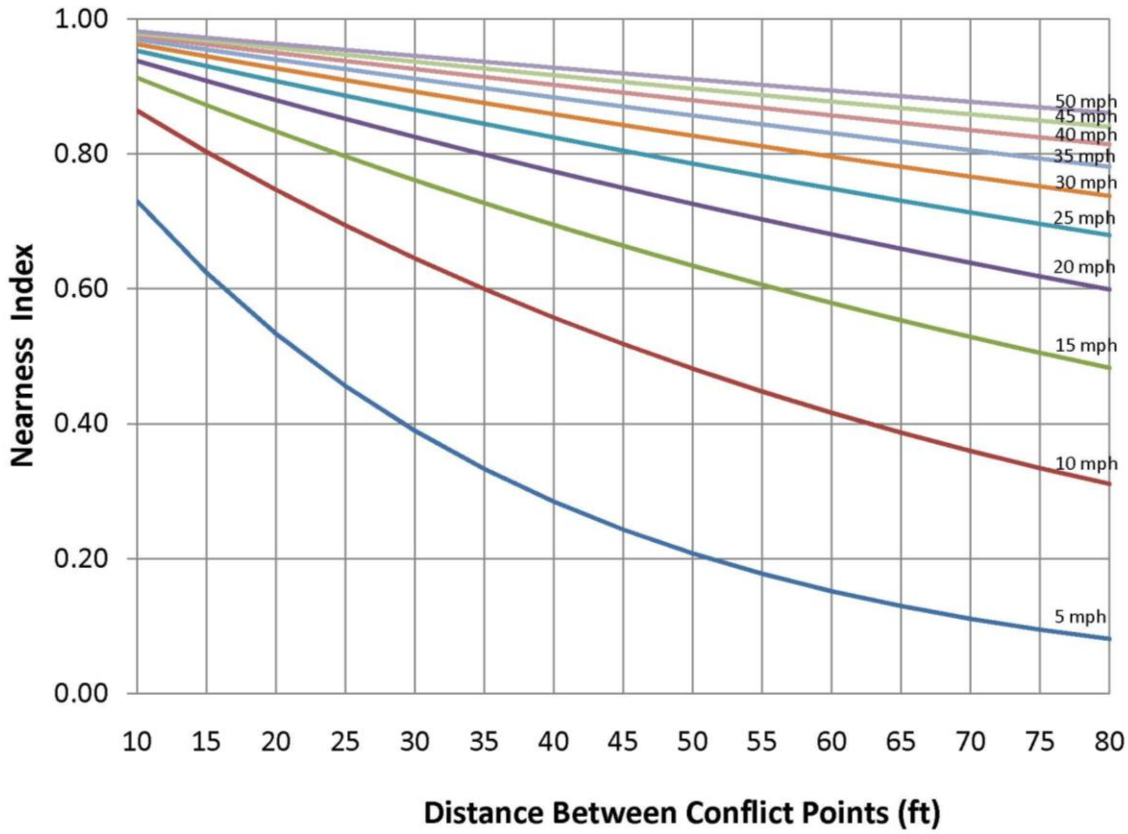


Figure 2. Nearness Index

Table 2. Alternative I Nearness Index Assessment

Movement	Prevailing Speed, S_0 (mph)	Distance, d (ft)	$NI = e^{-\frac{d}{SSD}}$
B to D	0 (stopped)	41	--
C to A	15	41	0.69
C to D	50	74	0.87

VOLUME AND NUMBER OF CONFLICTS

The expected number of conflicts that may occur should be based on the traffic exposure. For the purposes of this study, the authors have used the design hourly volume as a basis for identifying the magnitude of total conflicts. The conflicts occur when gaps in the major traffic stream are not large enough to accommodate the minor traffic stream operations of crossing, merging, or diverging. To determine the expected number of substandard gaps in the traffic stream, the probability that the required time (time to maneuver plus perception-reaction time) is less than the available time can be determined using the following relationship:

$$\Pr\,(t_{available} > [t_{required}) = e^{-V_{major}\left(\frac{t_{required}}{3600}\right)}$$

Where V_{major} = Major volume (vph) and $t_{required}$ = maneuver plus perception-reaction time in seconds

The number of gaps available along the arterial is then a factor of the probability of gaps and the major traffic volume. This value can be computed as:

$$Gaps = V_{major} e^{-V_{major}\left(\frac{t_{required}}{3600}\right)}$$

The proportion of movements that can occur successfully without a conflict can be determined as:

$$\text{Without Conflicts} = \frac{V_{major}\left[e^{-V_{major}\left(\frac{t_{required}}{3600}\right)}\right]}{V_{major}} = e^{-V_{major}\left(\frac{t_{required}}{3600}\right)}$$

The proportion of movements, therefore, that can be expected to experience conflicts resulting from minor movement vehicle operations is calculated as follows:

$$\text{Number of Conflicts} = N = V_{minor}\left[1 - e^{-V_{major}\left(\frac{t_{required}}{3600}\right)}\right]$$

The required time will differ for diverging, crossing, or merging conflict types. For the diverging conflict, the deceleration time plus the perception-reaction time should be included in the required time. Since we know the minor movement speed should be similar to the major movement speed minus the deceleration, we can represent this relationship as follows:

$$S_{minor} = S_{major} - \frac{(a)(t_{decel})}{1.47}$$

Where a = 11.2 ft/sec^2 and S = speed.

The total diverging time could then be determined by solving this equation for the deceleration time and adding the perception-reaction time and conversion factors as shown in the following equation:

$$t_{diverge} = \frac{1.47(S_{major} - S_{minor})}{a} + t_{pr}$$

Table 3 shows this diverging time equation as well as the crossing and merging times used for estimating the number of conflicts. The deceleration rate of 11.2 ft/sec^2 is a conservative value as 90-percent of drivers generally decelerate at or above this rate (*1*). Table 3 also demonstrates the relationship of the major and minor traffic volume for the specific conflict configuration.

To demonstrate the estimate for the number of conflicts, consider diverging conflict point "C" for Alternative I. The time to diverge can be calculated as:

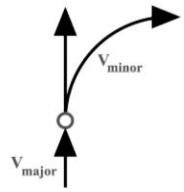
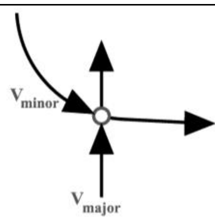
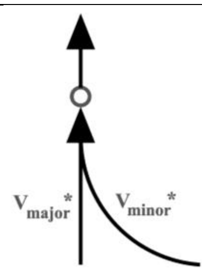
$$t_{diverge} = \frac{1.47(50-5)}{11.2} + 2.5 = 5.9 + 2.5 = 8.4 \text{ sec}$$

The number of conflicts can then be calculated as:

$$N = 80\left[1 - e^{-500\left(\frac{8.4}{3600}\right)}\right] = 55.1 \text{ conflicts/hr}$$

Once the number of conflicts for a specific location has been determined, this value can be combined with the ELC (previously identified) to determine the relative risk assessment index (RAI) for the specific conflict point as well as for the entire intersection. This RAI is developed in the following section.

Table 3. Time Estimation for Calculating the Number of Conflicts

Type	Schematic	Time, t (sec)
Diverge		$t_d = \frac{1.47(S_{major} - S_{minor})}{a} + t_{pr}$ Where S_{major} = Major [arterial] speed (mph) S_{minor} = Minor [diverging] vehicle speed (mph) $a = 11.2$ ft/sec^2 t_{pr} =perception reaction time (sec)
Crossing		$t_{crossing} = t_{maneuver} + t_{pr}$ Where $t_{maneuver}$ = 6.5 sec. [Approximate crossing speed per Highway Capacity Manual (2)] t_{pr} =perception reaction time (sec)
Merge		$t_{merge} = t_{acceleration} + t_{pr}$ Where $t_{acceleration}$ = 2 to 4.5 (assume 3 ft/sec^2) t_{pr} =perception reaction time (sec)

RISK ASSESSMENT INDEX

The intersection risk assessment index (RAI) is determined by multiplying the individual expected level of conflict values at each point (this is the previously defined ELC) times the actual anticipated conflicting volumes at that point. This relationship can be demonstrated by the following equation:

$$RAI_{INT} = \sum_{x} (N_x \times ELC_x)$$

Where N_x = number of conflicts at point x, and ELC_x = expected level of conflict at point x.

Table 4 summarizes the number of conflicts, ELC, and RAI for the intersection depicted in Alternative I.

Table 4. Number of Conflicts and Risk Assessment Index for Alternative I Intersection

Conflict Point	Type	Relative Speed, S (mph)	t (sec)	Major Volume, V_{Major} (vph)	Minor Volume, V_{Minor} (vph)	Number of Conflicts, N (conflicts/ hr)	ELC	Risk Assessment Index, RAI
A	Merge	15	3+2.5=5.5	80	80	9.2	0.022	0.20
B	Diverge	10	1.3+2.5=3.8	110	110	12.1	0.010	0.12
C	Diverge	45	5.9+2.5=8.4	500	80	55.1	0.401	22.09
D	Merge	40	3+2.5=5.5	420	110	47.4	0.212	10.05
							RAI_{INT}	32.46

The Alternative I RAI_{INT} value of 32.46 can be interpreted that there are approximately 32 equivalent HO-55 conflicts per hour for the T-intersection configuration, conflict orientation, and traffic volume condition. This value could then be contrasted to other RAI values with different geometric configurations to determine the relative level of risk introduced by alternative design treatments.

To demonstrate how the RAI can vary for different design treatments, the following Alternative II example depicts a more complex configuration.

EXAMPLE -- ALTERNATIVE II

In Figure 1, the authors introduced a T-intersection with a median break as a contrast to the Alternative I right-in right-out T-intersection design. The procedure used for Alternative I can be directly applied to the Alternative II configuration as demonstrated below.

Step 1. Calculate the LC for Alternative II

To calculate the LC, first determine the type of conflict, relative speed, speed adjustment factor, and the conflict orientation factor as input into the LC calculations (see Table 5).

Table 5. Alternative II Level of Conflict Values

Conflict Point	Type	Major Speed, $Speed_{Major}$ (mph)	Minor Speed, $Speed_{Minor}$ (mph)	Relative Speed, RS (mph)	f_{spd}	c	LC	ELC
A	Merge	15	15	15	0.074	0.4	0.030	0.030
B	Diverge	0	10	10	0.033	0.3	0.010	0.100
C	Diverge	50	15 (5**)	45	0.669	0.3	0.201	1.334
D	Merge	50	10	40	0.529	0.4	0.212	0.212
E	Crossing*	50	15	50*	0.826	0.6	0.496	1.203
F	Crossing*	50	10	50*	0.826	0.6	0.496	0.864
G	Crossing*	20	20	20*	0.132	0.6	0.079	0.669
H	Merge	50	20	30	0.298	0.4	0.119	0.119
I	Diverge	50	25	25	0.207	0.3	0.062	0.649
							ELC_{INT}	5.180

*Use larger speed for kinetic energy calculations (LC estimate)

**Speed vector for 15 mph exiting vehicle along arterial at point of exit is approximately 5 mph.

Step 2. Determine Nearness Index (assume combined perception-reaction time of 4 seconds)

Using the prevailing speed and the distance between the various conflict points, the NI can be calculated as shown in Table 6.

Step 3. Find the Effective Level of Conflict at Each Point

To determine the ELC_{INT}, add the ELC values for each conflict point. Example ELC calculations are shown below for conflict point "C" and "H." Since point "H" is a merge point without downstream conflict points, the value of $ELC_H = LC_H$.

$ELC_C = LC_C+(LC_A)(NI_{CA})+(LC_E)(NI_{CE})+(LC_F)(NI_{CF})+(LC_D)(NI_{CD})$

$= 0.201+(0.030)(0.69)+(0.496)(0.95)+(0.496)(0.92)+(0.212)(0.87) = 1.334$

$ELC_H = LC_H = 0.119$ (merge)

Table 6. Alternative II Nearness Index Assessment

Movement	Prevailing Speed, S_0 (mph)	Distance, d (ft)	$NI = e^{-\frac{d}{SSD}}$
B to D	0 (stopped)	41	--
B to F	0 (stopped)	26	--
B to G	15	36	0.73
B to H	25	72	0.71
F to G	15	10	0.91
F to H	25	46	0.80
G to H	25	36	0.84
C to A	15	41	0.69
C to E	50	32	0.95
C to F	50	42	0.92
C to D	50	74	0.87
E to F	50	10	0.98
E to D	50	42	0.93
F to D	50	32	0.95
I to G	25	36	0.84
I to E	25	46	0.80
I to A	25	72	0.71
G to E	20	10	0.94
G to A	20	36	0.80
E to A	15	26	0.80
I to H	50	80	0.86

Step 4. Interpretation of Alternative II ELC Value

The conflicts for this driveway configuration have the aggregate equivalent conflict measure of 5.18 head-on collisions at a speed of 55 mph. The conflict rate without a median break (see Alternative I) was 0.646 so that would equate to 12.5% less risk at a location without the median opening as compared to the location where the median break is present (Alternative II).

Step 5. Determine the Number of Conflicts and Intersection Risk Assessment Index

Using the required time (maneuver plus perception-reaction time) and the major and minor traffic volumes, the number of conflicts for Alternative II is then multiplied by the previously calculated ELC values (see Table 5) to determine the RAI at each conflict point. These values are then totaled to develop the RAI_{INT} for this location (see Table 7).

Step 6. Interpretation of the RAI_{INT}

The RAI_{INT} value of 314.23 can be interpreted as approximately 314 equivalent HO-55 conflicts per hour for the Alternative II T-intersection (with an uncontrolled median break). By comparison (to the Alternative I values), the inclusion of a median opening can increase the level of risk, based on equivalent HO-55 conflicts), by 314 divided by 32 or a value of 9.8 times that of a location with the controlled median design.

Table 7. Number of Conflicts and Risk Assessment Index for Alternative II Intersection

Conflict Point	Type	Relative Speed, S (mph)	Required time, t (sec)	Major Volume, V_{Major} (vph)	Minor Volume, V_{Minor} (vph)	Number of Conflicts, N (conflicts/ hr)	ELC	Risk Assessment Index, RAI
A	Merge	15	3+2.5=5.5	100	80	11.3	0.030	0.34
B	Diverge	10	1.3+2.5=3.8	250	110	25.5	0.100	2.55
C	Diverge	45	5.9+2.5=8.4	500	80	55.1	1.334	73.49
D	Merge	40	3+2.5=5.5	420	110	52.1	0.212	11.04
E	Crossing	50	6.5+2.5=9.0	420	100	65.0	1.203	78.20
F	Crossing	50	6.5+2.5=9.0	420	140	91.0	0.864	78.63
G	Crossing	20	6.5+2.5=9.0	140	100	29.5	0.669	19.76
H	Merge	30	3+2.5=5.5	500	140	84.0	0.119	10.00
I	Diverge	25	3.3+2.5=5.8	600	100	62.0	0.649	40.22
							RAI_{INT}	314.23

ADDITIONAL ISSUES FOR CONSIDERATION

Often a location does not have discrete conflict points but is characterized by typical movements that could be considered conflict paths. For example, at locations with multiple lanes, vehicles may change lanes or enter alternative lanes (such as a continuous left-turn lane) at staggered locations, and the resulting conflict points may not be separated by fixed distances. The driver's decisions to alter path may be based on prevailing traffic, physical driveway locations, or other factors. These staggered conflict paths will have varying perception-reaction times as well as deceleration rates.

Additional conflict paths can be expected with increased pedestrian and bicycle activity. Pedestrians may cross driveways (approaching from the left and the right) or traverse the road at multiple locations. Bicycles also create a conflict point where they cross the lane or lanes at the driveway intersection. These conflicts should be directly considered in the evaluation of risk; however, if the bicycle operates within a bicycle lane that is oriented parallel to the vehicle lane, an additional conflict path (and potential distraction) is introduced between turning motor vehicles and non-turning bicycles. Future enhancements to the risk assessment rating could potentially expand to incorporate these less specific conflicting pathways.

CONCLUSIONS

This paper introduces a structure for the risk assessment index rating tool for assessing conflicts at driveway locations. Historically the number of conflict points and their orientation has been used exclusively to compare the relative safety of proposed driveway construction configurations. This rating method extends the conflicts analysis using vehicle dynamics, site specific characteristics, and traffic volumes to provide a more comprehensive view of the relative safety of conflicts with various driveway configurations.

The authors have developed a measure of relative safety for conflict points that yields an estimate of the equivalent number of HO-55 collisions at each conflict point (the ELC value) as well as an intersection equivalent value (ELC_{INT}). The RAI then combines the equivalent number of head-on collisions at 55 mph with the expected number of conflicts at each point during the design hour to determine the aggregate RAI for the intersection. This value yields the expected number of equivalent HO-55 conflicts for the driveway per hour.

Ultimately, the ELC and RAI values should be used to evaluate the relative risk and effectiveness of various driveway configurations and designs. This information can then be useful in determine locations for driveways, median openings, intersections, and their associated orientations.

REFERENCES

1. AASHTO (2004). *A Policy on Geometric Design of Highways and Streets.* Washington, DC, 896 pages
2. Transportation Research Board (2000). *Highway Capacity Manual*. Washington, DC.