A Programmable Procedure to Calculate Number of Traffic Conflict Points at Highway Intersections

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ABSTRACT

Traffic conflict points at intersections are the points at which traffic movements intersect (including crossing, merge, and diverge). Numbers and distribution of conflict points have been used to evaluate intersection access management designs and safety performance. Traditionally, determination of numbers of conflict points for different traffic movements has been based on manual methods, which causes the difficulty for computerized procedures to evaluate safety performance of different access management designs. Sometimes, a programmable procedure may provide better solutions as compared to manual methods. This paper presents a programmable procedure for the calculation of numbers of conflict points, which could be used as a basis for computerized procedure. Concepts of virtual movement lanes and intersection quadrants are introduced to specify types of intersections, traffic lane configurations, and traffic movement regulations. Based on the concepts, the calculation models for traffic conflict points at signalized and unsignalized intersections can be obtained. To support the procedure, case studies are presented in the paper. The procedure presented in the paper can be programmed into a computer program for the purpose of computerized evaluation of intersection safety and design performance of different access management or control approaches.

Keywords: Intersections, Conflict Points, Programmable Procedures, Traffic Paths, Traffic Flow Movements

INTRODUCTION

Highway intersections have been considered the areas with much higher potential for traffic crashes as compared to other highway segments. The main reason for this is that there are much more traffic conflict points inside intersections, which could result in more complicated driving maneuvers, meaning more traffic conflicts (traffic conflicts and traffic conflict points are different concepts). According to a study by Minnesota Department of Transportation, a four-way intersection (as shown in Figure 1) with 16 crossing conflict points, 8 merge conflict points, and 8 diverge conflict points could have an annual average crash rate of 0.4 (crashes per million vehicles). However, if this intersection is converted into a directional median opening with 2 crossing conflict points, 4 merge conflict points, and 4 diverge conflict points, the annual average crash rate is reduced to 0.2 *(1)*. This means that the reduction in conflict points could result in the reduction in crash rates.

Conflict points are parts of the main reasons for intersection crashes. Many research studies have used conflict points and corresponding severity characteristics to evaluate intersection safety performance *(2)*. In 2009, Lu developed models for level of safety services at unsignalized intersections *(3)*. Lu's models are based on numbers and types of conflict points with the adjustments from other conditions related to traffic flow, roadways, and controls. With given numbers and types of conflict points as well as adjustment factors, intersection safety performance can be evaluated by level of safety services. Some research studies have been performed to evaluate safety performance of roundabouts or intersections based on traffic conflict points between motorized vehicles, between motorized vehicles and non-motorized vehicles, and between motorized vehicles and pedestrians *(4, 5, 6)*. In 2009, in his dissertation research, Shen proposed a model to evaluate intersection driving maneuverability degree *(7)*. In Shen's model, numbers of different types of conflict points and corresponding conflicting probabilities at these conflict points are combined so that quantitative models can be used for optimized design of intersections with the considerations of operations and safety performance. In safety improvement programs, reduction or separation of traffic conflict points are considered one of the major ways to improve intersection safety. Florida Department of Transportation emphasizes the control ways to reduce and separate traffic conflict points in its strategic highway safety plan *(8)*. Analytical approaches of traffic conflict points have been used to evaluate traffic U-turn movements and safety performance at unsignalized median openings and conclusions have been made to indicate that analytical approaches are useful ways for such applications *(9, 10, 11)*.

Currently, in order to determine conflict points, the common way is to draw intersection geometrics and traffic paths, and intersecting points (including crossing, merge, and diverge) of all traffic movement paths are manually counted. However, for a four-way unsignalized intersection with two-way-two-lane approaches, the following equations can be used to calculate conflict points *(11)*:

$$N_c = n^2(n-1)(n-2)/6 \tag{1}$$

$$N_m = N_d = n(n-2) \tag{2}$$

where:

N_c – *number of crossing conflict points,*

N_m – *number of merge conflict points,*

N_d – *number of diverge conflict points, and*

n – *number of intersecting approaches (3-5 approaches).*

The above equations are only useful for a four-way unsignalized intersection with two-way-two-lane approaches. In real situation, there are many types of intersections with different control regulations, approaches, and lane configurations. It is very difficult to use closed mathematic forms to calculate numbers of different types of conflict points.

The research presented in this paper was performed to develop a programmable procedure and models to calculate numbers of traffic conflict points for different movements. The concepts of intersection quadrants and virtual movement lanes are introduced in the procedure to determine intersection traffic movement paths. Based on traffic movement paths, models are used to calculate numbers of traffic conflict points for different traffic movements.

MATHODOLOGY

A traffic conflict point is the intersecting point between different traffic movement paths. Traffic conflict points can be grouped into crossing, merge, and diverge types. Based on such a definition, a conflict point needs to meet the following conditions: (1) there are different traffic flows moving towards different directions, (2) these different traffic flows intersect at the same time, and (3) these different traffic flows intersect at the same location (point). Thus, to obtain numbers of traffic conflict points, two steps are needed:

(1) For a given time moment, number of traffic flow paths in different directions should be calculated. This can be done based on the number of lanes in each approach, traffic control regulations, and right of way of each traffic flow.

(2) The moving regulations of traffic flows intersecting at a given point should be determined. The formation of a traffic conflict point depends on whether or not different traffic flows intersect at the given point.

With such considerations, if the number of traffic flow movement paths at each approach is determined, different types of traffic conflict points could be calculated.

Concept of Intersection Quadrants

The so called intersection quadrant refers to the two-dimension treatment of the physical area of an intersection so that each approaching area inside the intersection can be distinguished. A four-way right-angle intersection can be divided into four large intersection quadrants. Each large quadrant consists of two small quadrants, including one entering quadrant and one departure quadrant as shown in Figure 2.a. Thus, a four-way right-angle intersection has four entering quadrants and four departure quadrants with the coordination lines intersecting at the center point of the intersection. For a T-type intersection, since there are only three approaches, only 3 entering quadrants (quadrants 1, 3, 5) and 3 departure quadrants (quadrants 2, 4, 8) are considered., and quadrants 6 and 7 are not used when calculating traffic conflict points as shown in Figure 2.b. It needs to state that in Figure 2, roadway 1 is considered the major road and roadway 2 is considered the minor road. In real situation, there are many different forms of intersections, such as Y-type and X-type intersections. However, the analysis concept and procedures are similar.

Concept of Virtual Movement Lanes

Virtual movement lanes refer to the traffic flow paths from an entering lane at an intersection, such as through movement, left-turn, and right-turn paths. For example, an entering lane allows traffic make through movement and left-turn movement, this lane is considered having two virtual movement lanes leaving the entering lane. One entering lane can have at most three virtual movement lanes, including one through movement, a left-turn, and one right-turn virtual movement lanes. If a lane is used only for a particular movement, this lane can only result in one virtual movement lane. If two traffic movements share one lane, this lane results in two virtual movement lanes. In general, the number of virtual movement lanes resulting from a given lane is equal to the number of allowed traffic movement paths in this lane.

To determine virtual movement lanes, the following variables are defined:

N^0_{lt} – number of entering lanes with left-turn and through movements,

N^0_{tr} – number of entering lanes with through and right-turn movements,

N^0_{ltr} – number of entering lanes with left-turn, through, and right-turn movements,

N^0_{lr} – number of entering lanes with left-turn and right-turn movements,

N^0_{l} – number of entering lanes with exclusive left-turn movements,

N^0_{t} – number of entering lanes with exclusive through movements,

N^0_{r} – number of entering lanes with exclusive right-turn movements, and

N^0_{dl} – number of departure lanes.

Table 1 is used to record numbers of entering and departure lanes in order to determine conflict points.

According to the definition discussed previously, total number of virtual movement lanes for a given movement direction in a given entering quadrant is the summation of the numbers of virtual movement lanes in that movement direction of all entering lanes in that quadrant. Thus the following equations can be used to calculate number of virtual movement lanes in each movement direction in a particular entering quadrant:

$$F^0_l = N^0_{lt} + N^0_{lr} + N^0_{ltr} + N^0_l \quad (3)$$

$$F^0_t = N^0_{lt} + N^0_{tr} + N^0_{ltr} + N^0_t \quad (4)$$

$$F^0_r = N^0_{lr} + N^0_{tr} + N^0_{ltr} + N^0_r \quad (5)$$

where: F^0_l, F^0_t, and F^0_r represent numbers of virtual movement lanes for left-turn, through, and right-turn movements in the given entering quadrant, respectively. By the same method, number of virtual movement lanes for left-turn, through, and right-turn movements in all entering quadrants can be obtained. In real applications, a table is needed to summarize numbers of virtual movement lanes in each entering quadrant. Table 2 can be used for this purpose.

Calculation Models

Calculation procedures and models are based on the number of virtual movement lanes in each entering quadrant. The way to obtain number of virtual movement lanes in each entering quadrant is described in previous sections. The following sections present the procedures to calculate number of conflict points for unsignalized intersections only. The same procedures can also be applied for signalized intersections. The only difference is that traffic movements in signalized intersections need to be separated for different signal phases and the procedure needs to be applied for each signal phase. Actually, for a given signal phase, the intersection can be considered an unsignalized intersection with given traffic regulations applied to corresponding entering approach. In the following sections, a four-way right-angle intersection is used as an example. The procedures for other types of intersections are similar.

Crossing Conflict Points

Crossing conflict points only exist at the intersecting points of the traffic movements, such as left-turn path vs. left-turn path, through movement vs. through movement path, and left-turn path vs. through movement path. As the first step, quadrant 1 (see Figure 2) is considered as a basis. Number of crossing conflict points between traffic movements from this quadrant and from other quadrants (quadrants 3, 5, and 7) can be calculated by the following equation:

$$NCP_{c1} = F_{1l} \times F_{3l} + F_{1l} \times F_{5t} + F_{1l} \times F_{7l} + F_{1l} \times F_{7t} + F_{1t} \times F_{3l} + F_{1t} \times F_{3t} + F_{1t} \times F_{5l} + F_{1t} \times F_{7t} \quad (6)$$

where:

NCP_{c1} - conflict points between traffic movements from this quadrant and from other quadrants,

F_{1l} - number of left-turning virtual movement lanes in quadrant 1,

F_{1t} - number of through movement virtual movement lanes in quadrant 1,

F_{3l} - number of left-turning virtual movement lanes in quadrant 3,

F_{3t} - number of through movement virtual movement lanes in quadrant 3,

F_{5l} - number of left-turning virtual movement lanes in quadrant 5,

F_{5t} - number of through movement virtual movement lanes in quadrant 5,

F_{7l} - number of left-turning virtual movement lanes in quadrant 7, and

F_{7t} - number of through movement virtual movement lanes in quadrant 7.

In the second step, quadrant 3 is considered as the basis. Similarly, number of crossing conflict points between traffic movements from this quadrant and from other quadrants (quadrants 5 and 7) can be calculated by the following equation:

$$NCP_{c2} = F_{3l} \times F_{5l} + F_{3l} \times F_{7t} + F_{3t} \times F_{5l} + F_{3t} \times F_{5t} + F_{3t} \times F_{7l} \quad (7)$$

In the third step, quadrant 5 is considered as the basis, and number of crossing conflict points between traffic movements from this quadrant and from quadrants 7 can be calculated by the following equation:

$$NCP_{c3} = F_{5l} \times F_{7l} + F_{5t} \times F_{7l} + F_{5t} \times F_{7t} \quad (8)$$

In the final step, the total number of crossing conflict points can be obtained by the following equation:

$$\begin{aligned} NCP_c &= NCP_{c1} + NCP_{c2} + NCP_{c3} \\ &= F_{1l} \times F_{3l} + F_{1l} \times F_{5t} + F_{1l} \times F_{7l} + F_{1l} \times F_{7t} + F_{1t} \times F_{3l} + F_{1t} \times F_{3t} \\ &\quad + F_{1t} \times F_{5l} + F_{1t} \times F_{7t} + F_{3l} \times F_{5l} + F_{3l} \times F_{7t} + F_{3t} \times F_{5l} + F_{3t} \times F_{5t} \\ &\quad + F_{3t} \times F_{7l} + F_{5l} \times F_{7l} + F_{5t} \times F_{7l} + F_{5t} \times F_{7t} \end{aligned} \quad (9)$$

Merge Conflict Points

Merge conflict points are distributed at departure quadrants of an intersection. The left-turn, through, and right-turn traffic movements from other entering quadrants merge to a departure quadrant. If the number of virtual movement lanes from other entering quadrants to enter to the departure quadrant is equal to or less than the number of departure lanes at the departure quadrant, each virtual movement lane can lead to at least one departure lane and there is no merging traffic movement. Thus, there is no merge conflict point at the departure quadrant. Otherwise, there exist merge conflict points at the departure quadrant, and the number of merge conflict points at the departure quadrant is the difference between the number of virtual movement lanes from other entering quadrants and the number of departure lanes at the departure quadrant. From Figure 1, it can be understood that the number of merge conflict points at quadrant 8 is:

$$NCP_{i1} = \begin{cases} F_{3l} + F_{5t} + F_{7r} - N^0{}_{8dl} & NCP_{i1} \geq 0 \\ 0 & NCP_{i1} = 0 \end{cases} \tag{10}$$

where:

NCP_{i1} - number of merge conflict points at quadrant 8,

F_{7r} - number of right-turning virtual movement lanes in quadrant 7,

$N^0{}_{8dl}$ - number of departure lanes in quadrant 8.

Other variables are defined previously. By the same way, numbers of merge conflict points in quadrants 2, 4, and 6 can be calculated by the following equations:

$$NCP_{i2} = \begin{cases} F_{5l} + F_{7t} + F_{1r} - N^0{}_{2dl} & NCP_{i2} \geq 0 \\ 0 & NCP_{i2} = 0 \end{cases} \tag{11}$$

$$NCP_{i3} = \begin{cases} F_{7l} + F_{1t} + F_{3r} - N^0{}_{4dl} & NCP_{i3} \geq 0 \\ 0 & NCP_{i3} = 0 \end{cases} \tag{12}$$

$$NCP_{i4} = \begin{cases} F_{1l} + F_{3t} + F_{5r} - N^0{}_{6dl} & NCP_{i4} \geq 0 \\ 0 & NCP_{i4} = 0 \end{cases} \tag{13}$$

where:

NCP_{i2} - number of merge conflict points at quadrant 2,

F_{1r} - number of right-turning virtual movement lanes in quadrant 1,

$N^0{}_{2dl}$ - number of virtual lanes in quadrant 2,

NCP_{i3} - number of merge conflict points at quadrant 4,

F_{3r} - number of right-turning virtual movement lanes in quadrant 3

$N^{0}{}_{4dl}$ - number of departure lanes in quadrant 4,

NCP_{i4} - number of merge conflict points at quadrant 6,

F_{5r} - number of right-turning virtual movement lanes in quadrant 5, and

$N^{0}{}_{6dl}$ - number of departure lanes in quadrant 6.

Other variables are defined previously. Thus, the total number of merge conflict points (NCP_i) at the intersection can be calculated as follows:

$$NCP_i = NCP_{i1} + NCP_{i2} + NCP_{i3} + NCP_{i4} \qquad (14)$$

Diverge Conflict Points

Diverge conflict points are distributed in entering quadrants. Number of diverge conflict points can be calculated based on number of entering lanes with multiple movements in the same quadrant. The following equations are to calculate numbers of diverge conflict points in all entering quadrants.

Diverge conflict points in entering quadrant 1 can be calculated by the following equation:

$$NCP_{d1} = N^{0}{}_{1lt} + N^{0}{}_{1lr} + N^{0}{}_{1tr} + 2N^{0}{}_{1ltr} \qquad (15)$$

where:

$N^{0}{}_{1lt}$ - number of lanes shared by left-turning and through movements in quadrant 1,

$N^{0}{}_{1lr}$ - number of lanes shared by left-turning and right-turning movements in quadrant 1,

$N^{0}{}_{1tr}$ - number of lanes shared by right-turning and through movements in quadrant 1, and

$N^{0}{}_{1ltr}$ - number of lanes shared by left-turning, right-turning, and through movements in quadrant 1.

Diverge conflict points in entering quadrant 3 can be calculated by the following equation:

$$NCP_{d2} = N^{0}{}_{3lt} + N^{0}{}_{3lr} + N^{0}{}_{3tr} + 2N^{0}{}_{3ltr} \qquad (16)$$

where:

$N^{0}{}_{3lt}$ - number of lanes shared by left-turning and through movements in quadrant 3,

$N^{0}{}_{3lr}$ - number of lanes shared by left-turning and right-turning movements in quadrant 3,

$N^{0}{}_{3tr}$ - number of lanes shared by right-turning and through movements in quadrant 3, and

$N^0{}_{3ltr}$ - number of lanes shared by left-turning, right-turning, and through movements in quadrant 3.

Diverge conflict points in entering quadrant 5 can be calculated by the following equation:

$$NCP_{d3} = N^0{}_{5lt} + N^0{}_{5lr} + N^0{}_{5tr} + 2N^0{}_{5ltr} \tag{17}$$

where:

$N^0{}_{5lt}$ - number of lanes shared by left-turning and through movements in quadrant 5,

$N^0{}_{5lr}$ - number of lanes shared by left-turning and right-turning movements in quadrant 5,

$N^0{}_{5tr}$ - number of lanes shared by right-turning and through movements in quadrant 5, and

$N^0{}_{5ltr}$ - number of lanes shared by left-turning, right-turning, and through movements in quadrant 5.

Finally, number of diverge conflict points in entering quadrant 7 can be calculated by the following equation:

$$NCP_{d4} = N^0{}_{7lt} + N^0{}_{7lr} + N^0{}_{7tr} + 2N^0{}_{7ltr} \tag{18}$$

where:

$N^0{}_{7lt}$ - number of lanes shared by left-turning and through movements in quadrant 7,

$N^0{}_{7lr}$ - number of lanes shared by left-turning and right-turning movements in quadrant 7,

$N^0{}_{7tr}$ - number of lanes shared by right-turning and through movements in quadrant 7, and

$N^0{}_{7ltr}$ - number of lanes shared by left-turning, right-turning, and through movements in quadrant 7.

To obtain the total number of diverge conflict points *(NCP_d)*, the following equation is used:

$$NCP_d = NCP_{d1} + NCP_{d2} + NCP_{d3} + NCP_{d4} \tag{19}$$

CASE STUDIES

To demonstrate and verify the procedures described above, several case studies were performed. In the experiments, signalized intersections with two-phase and four-phase plans and unsignalized intersections were selected to represent the most popular situation. The models and procedures describer previously are applied to determine numbers of conflict points. Meanwhile, manual ways to count numbers of conflict points are also used to verify whether or not correct results can be obtained.

Intersection Information

Four intersections close to Nanjing area in Jiangsu province were selected. These sites include: (1) the intersection of

Province Road S239 vs. Province Road S240 with a two-phase signals, (2) the intersection of Country Road G 104 vs. Chengxu Road with three-phase signals, (3) the unsignalized intersection of Province Road 123 vs. Zhengfang West Road, and (4) the unsignalized intersection of Country Road 104 vs. Kaiyuan Road. Intersection information and lane distributions are shown in Tables 3 and 4.

Determination of Conflict Points

The procedures and models presented previously are applied to determine numbers of conflict points, including crossing, merge, and diverge conflict points for all these intersections. Actually, the procedures and models can be implemented by a computer program to automatically complete the calculation process. Based on the information presented in Tables 3 and 4, numbers of entering lanes for different traffic movements and lane share combination and numbers of departure lanes are shown in Table 5. It should be noted that for the signalized intersections, number of entering lanes should be considered for different signal phases. If traffic movement in an approaching direction is not allowed for a given signal phase, there is no entering lanes in that direction for the particular phase.

According to Equations 3, 4, and 5, numbers of virtual movement lanes in different movement directions in each entering quadrant are calculated and results are shown in Table 6. Equations 6 through 19 are used to calculate numbers of conflict points at each intersection and results are presented in Table 7.

Comparison with Manual Method

Manual methods are used to count number of conflict points at these intersections. Figure 3 shows the geometrics and traffic control regulations of these intersections. In the same figure, numbers of conflict points at each intersection are presented. It is clearly indicated that the results from the programmable procedures and the manual methods fully match, meaning the programmable method can result in correct calculation of numbers of conflict points.

CONCLUSIONS

As stated before, if lane distributions and traffic movement regulations (including signal phasing) are given, the procedures and models presented in the paper can be programmed for the automatic determination of numbers of conflict points at an intersection, which makes it possible to evaluate different intersection access management designs with a computerized program. It can be imaged that if the determination of numbers of intersection traffic conflict points can be programmed, many evaluation and design applications, such as access management technique assessment and evaluation of level of safety services, can be much easier.

The models and procedures described in the paper cannot be applied to roundabout intersections as the definitions of virtual movement lanes and quadrants may not be directly used in cases of roundabout intersections. However, the methodology and concept can be used for other types of intersections or more complicated cases, such as roundabout intersections. There is more fine work needed to standardize the procedures and models with application boundaries specified.

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Table 1. Summary Form for Number of Lanes in Each Approach at an Intersection

Approaches	Number of Entering Lanes							Number of Departure Lanes
	N^0_{lr}	N^0_{tr}	N^0_{ltr}	N^0_{lr}	N^0_{l}	N^0_{t}	N^0_{r}	N^0_{dl}
A								
B								
C								
D								

Table 2. A Table to Summarize Virtual Movement Lanes

Entering Quadrants	F^0_l	F^0_t	F^0_r
A			
B			
C			
D			

Table 3. Traffic Control and Regulations of Experimental Intersections

Intersections	Control	Phasing Plans
S239 vs. S240	Signalized	Phase 1: East-West Bound (Left Turns, Through Movement, and Right Turns) and North-South Bound (Right Turns) Phase 2: North-South Bound (Left-Turns, Through Movement, and Right Turns) and East-West Bound (Right Turns)
G104 vs. Chengxu Rd.	Signalized	Phase 1: East-West Bound (Left-Turns and Right-Turns) and North-South Bound (Right-Turns) Phase 2: East-West Bound (Through Movement and Right-Turns) and North-South Bound (Right-Turns) Phase 3: North-South Bound (Left-Turns, Through Movement, and Right-Turns) and East-West Bound (Right-Turns)
S123 vs. Zhengfang West Rd.	Unsignalized	N/A
G104 vs. Kaiyuan Rd.	Unsignalized	N/A

Table 4. Lane Distribution of Experimental Intersections (L: Left-Turn, T: Through Movement, & R: Right-Turn)

Intersections	Approaches	Entering Lanes						Number of Departure Lanes
		Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6	
S239 vs. S240	A	*L & T*	*T & R*					2
	B	*L*	*T & R*					2
	C	*L & T*	*T & R*					2
	D	*L & T*	*T & R*					2
G104 vs. Chengxu Rd.	A	*L*	*T*	*T*	*T*	*T*	*R*	4
	B	*L & T*	*R*					2
	C	*L*	*T*	*T*	*T*	*T*	*R*	4
	D	*L*	*T*	*R*				2
S123 vs. Zhengfang West Rd.	A	*L & T*	*T & R*					2
	B	*L & T & R*						2
	C	*L & T*	*T & R*					2
	D	*L & T & R*						2
G104 vs. Kaiyuan Rd.	A	*L*	*T*	*T*	*T & R*			4
	B	*L & T*	*T & R*					2
	C	*L*	*T*	*T*	*T & R*			4
	D	*L & T*	*T & R*					2

Table 5. Summary of Number of Lanes in Each Approach of Experimental Intersections

Intersections		Approaches	Number of Entering Lanes							Number of Departure Lanes
			N^0_{lt}	N^0_{tr}	N^0_{ltr}	N^0_{lr}	N^0_{l}	N^0_{t}	N^0_{r}	N^0_{dl}
S239 vs. S240	Phase I	A	1	1	0	0	0	0	0	2
		B	0	0	0	0	0	0	1	2
		C	1	1	0	0	0	0	0	2
		D	0	0	0	0	0	0	1	2
	Phase II	A	0	0	0	0	0	0	1	2
		B	0	1	0	0	1	0	0	2
		C	0	0	0	0	0	0	1	2
		D	1	1	0	0	0	0	0	2
G104 vs. Chengxu rd.	Phase I	A	0	0	0	0	1	0	1	4
		B	0	0	0	0	0	0	1	2
		C	0	0	0	0	1	0	1	4
		D	0	0	0	0	0	0	1	2
	Phase II	A	0	0	0	0	0	4	1	4
		B	0	0	0	0	0	0	1	2
		C	0	0	0	0	0	4	1	4
		D	0	0	0	0	0	0	1	2
	Phase III	A	0	0	0	0	0	0	1	4
		B	1	0	0	0	0	0	1	2
		C	0	0	0	0	0	0	1	4
		D	0	0	0	0	1	1	1	2
S123 vs. Zhengfang West Rd.		A	0	0	1	0	0	0	0	1
		B	1	1	0	0	0	0	0	2
		C	0	0	1	0	0	0	0	1
		D	1	1	0	0	0	0	0	2
G104vs. Kaiyuan Rd.		A	0	1	0	0	1	2	0	4
		B	1	1	0	0	0	0	0	2
		C	0	1	0	0	1	2	0	4
		D	1	1	0	0	0	0	0	2

Table 6. Summary of Virtual Movement Lanes in Each Quadrant

Intersections		Quadrants	Number of Virtual Movement Lanes		
			F_l	F_t	F_r
S239 vs. S240	Phase I	1	1	2	1
		3	0	0	1
		5	1	2	1
		7	0	0	1
	Phase II	1	0	0	1
		3	1	1	1
		5	0	0	1
		7	1	2	1
G104 vs. Chengxu Rd.	Phase I	1	1	0	1
		3	0	0	1
		5	1	0	1
		7	0	0	1
	Phase II	1	0	4	1
		3	0	0	1
		5	0	4	1
		7	0	0	1
	Phase III	1	0	0	1
		3	1	1	1
		5	0	0	1
		7	1	1	1
S123vs. Zhengfang West Rd.		1	1	1	1
		3	1	2	1
		5	1	1	1
		7	1	2	1
G104 vs. Kaiyuan Rd.		1	1	3	1
		3	1	2	1
		5	1	3	1
		7	1	2	1

Table 7. Summary of Number of Conflict Points

Intersections		Number of Conflict Points		
		Crossing	Merge	Diverge
S239 vs. S240	Phase I	4	2	4
	Phase II	3	1	3
G104 vs. Chengxu Rd.	Phase I	0	0	0
	Phase II	0	2	0
	Phase III	2	0	1
S123 vs. Chengfang West Rd.		24	8	8
G104 vs. Kaiyuan Rd.		48	6	6

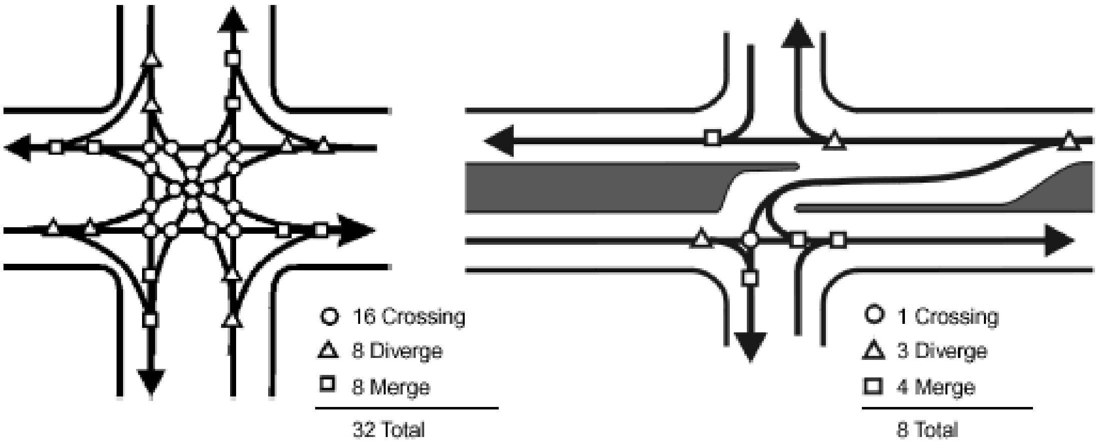
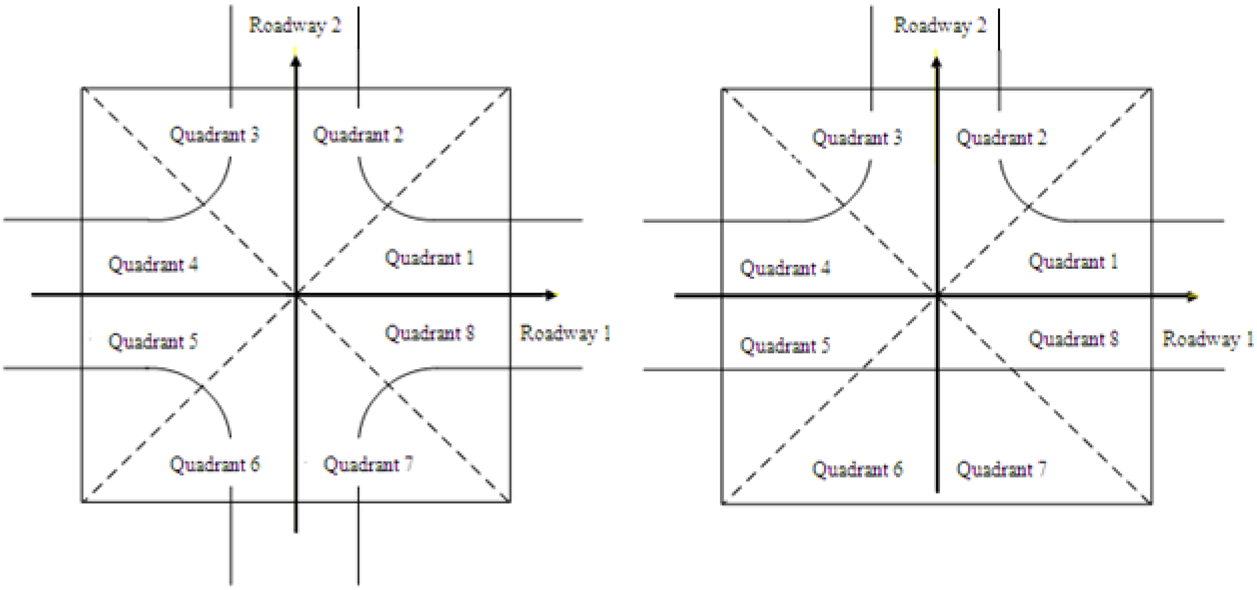


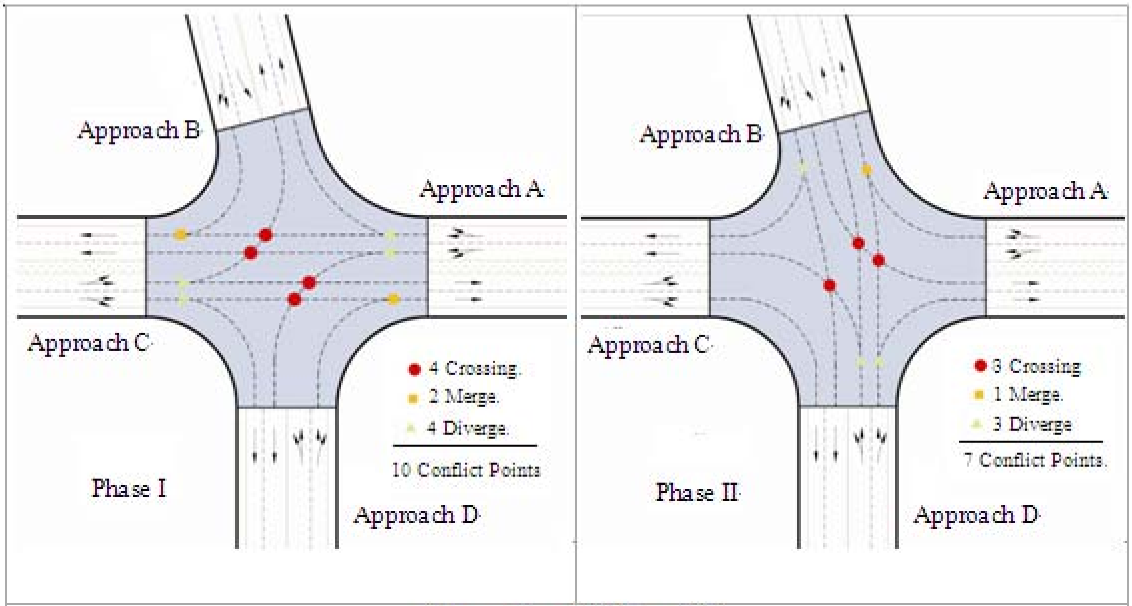
Figure 1. Vehicular Conflict Points at a Typical Four-Way Intersection Vs. a Directional Median Opening



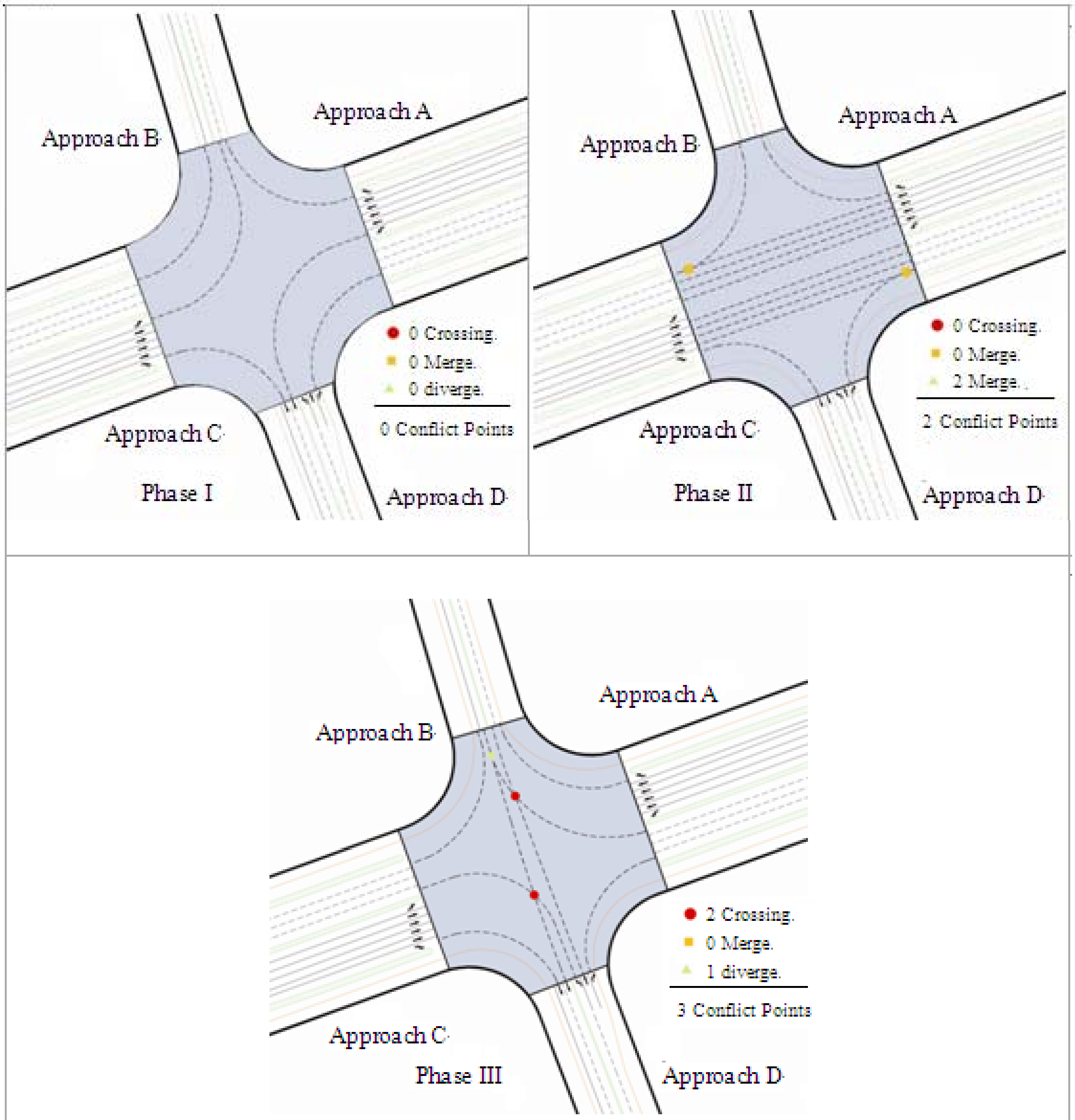
a. Four-Way Right-Angle Intersection

b. T-Type Intersection

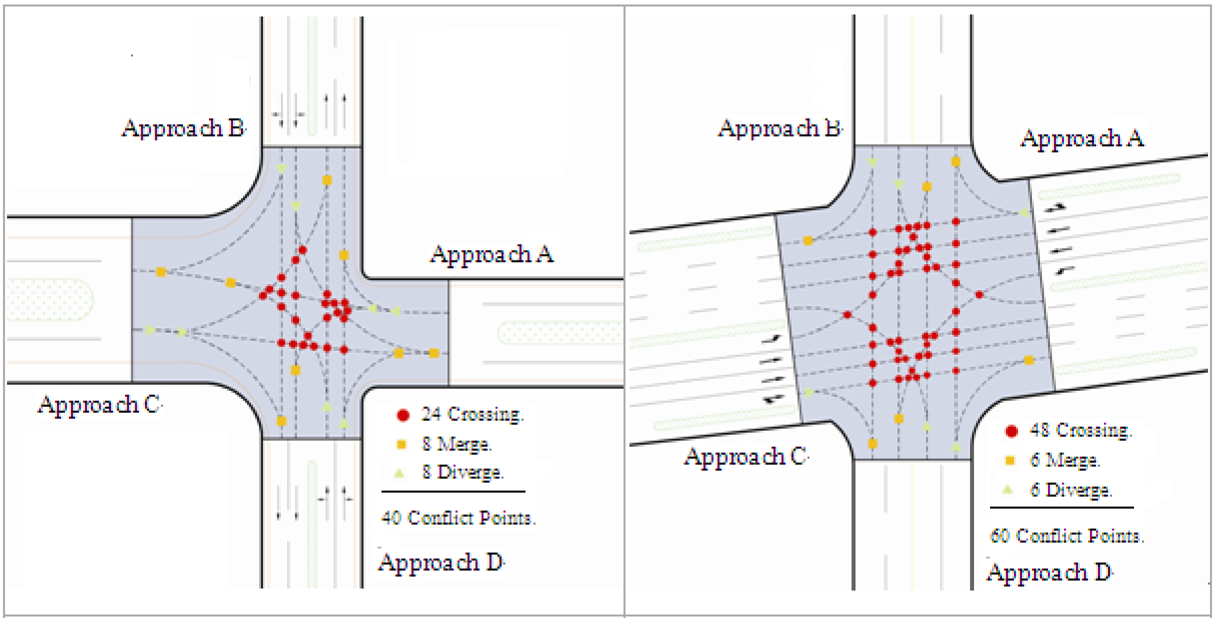
Figure 2. Concept of Intersection Quadrants



a. Intersection of S240 vs. S239



b. Intersection of G104 vs. Chengxu Road



c. Intersection of S123 vs. Zhengfang West Road	d. Intersection of G104 vs. Kaiyuan Road

Figure 3. Geometrics and Traffic Control Regulations of Experimental Intersections