Diverging Diamond Interchange and Double Crossover Intersection – Vehicle and Pedestrian Performance

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Joe Bared
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Praveen K. Edara,
Department of Civil and Environmental Engineering,
Virginia Polytechnic Institute and State University,
Falls Church, VA
praveen@vt.edu

Joe G. Bared,
Federal Highway Administration,
Turner-Fairbank Highway Research Center,
McLean, VA
Joe.Bared@fhwa.dot.gov

Ramanujan Jagannathan,
BMI-SG
Vienna, VA
rjagannathan@bmisg.com

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Praveen K. Edara, Virginia Tech
Joe G. Bared, FHWA
Ramanujan Jagannathan, BMI-SG

Transportation planners and traffic engineers are facing the challenge of inventing ways to mitigate congestion during peak hours. Alleviating delays and improving safety for passengers and pedestrians is the primary motive. One way of achieving this objective is to search for alternative intersection and interchange designs. This paper presents the results of a study on two new alternate designs – Double Crossover Intersection and Diverging Diamond Interchange. These designs are studied for different traffic scenarios using traffic simulation and the results showed better performance during peak hours when compared to similar corresponding conventional designs. Better performance includes, lesser delays, smaller queues, and higher throughput; resulting in better level of service.

BACKGROUND

Transportation planners and traffic engineers are facing the challenge of mitigating congestion during peak hours and at lower costs. Alleviating delays and improving safety for motor vehicles and pedestrians are primary motives. In urban areas, the land available for constructing roads is less and hence should be used more judiciously by designing roads, intersections, and interchanges that occupy less right-of-way. One way of achieving all these objectives is to search for alternative intersection designs.

Researchers have developed several innovative intersection designs in the past to address these problems. These designs include the quadrant roadway intersection, median U-turn, superstreet median, jughandle, split intersection, and the continuous flow intersection (CFI). The most influential factor in the intersection performance for heavy flows is achieved by reducing the number of phases in the signal cycle. The CFI especially is finding increasing acceptance in the United States lately (*1*).

Chlewicki (*2*) suggested two new designs for intersection and interchange designs - the Synchronized Split-Phasing (SSP) Intersection and the Diverging Diamond Interchange (DDI). As in the CFI, SSP design also disperses the flow of traffic before reaching the main intersection. The synchronized split phasing design allows both the through and the left movements to crossover prior to the intersection (see Figure 1).

The main goal of the DDI design is to better accommodate left-turn movements and hence eliminate a phase in the signal cycle. Figure 1 (b) shows the layout of the diverging diamond interchange. The freeway portion does not change but the movements off the ramps change for left-turns. In a DDI, through and left-turn traffic on the crossroad maneuver differently from a conventional diamond interchange as the traffic crosses to the opposite side in between the ramp terminals.

Chlewicki (*2*) discusses the simulation tests performed for a case study intersection and interchange using Synchro as the simulation tool. Results showed that the SSP and the DDI designs outperform similar corresponding conventional designs. In his conclusion, Chlewicki (*2*) discusses the future scope of research including analysis of different volume ratios and turning movement ratios, the speeds and superelevations to see how fast vehicles can travel practically in the crossover movements.

In this paper, we further analyze the designs presented by Chlewicki (*2*). Four different traffic scenarios are considered and pedestrian performance is simulated for one case. A comparison is done with conventional intersection and interchange designs. Additional analyses related to the capacities of these innovative designs are also performed and results reported.

In the first section of our paper, we describe detailed designs of the intersection and interchange. In the second section, we describe our analysis methodology including the simulation tool used, signal setting criteria, performance measures, and the four different scenarios modeled. The third section contains our findings; and the fourth section contains our conclusions and recommendations for future research.

DESCRIPTION OF THE DESIGNS

Double Crossover Intersection (DXI)

In this paper, we will use DXI as a more descriptive name than synchronized split phasing. Figure 2 shows the layout of a Double Crossover Intersection. The Eastbound (EB) traffic (through and left-turners) crosses over to the left side at signalized intersection A, while the right-turners use the dedicated right lane before reaching A. The crossed traffic will crossover back to the right side at signalized intersection C. The Westbound (WB) traffic also crosses over in a similar way. At intersection B, there is one through lane and one through+left-turn lane. No dedicated left-turn lanes are provided. Right-turn lanes are required for EB and WB traffic. Merging lanes for the Northbound (NB) and Southbound (SB) for right-turn movements are required. Radii of crossover movements can range from 150 ft to 200 ft and that of the left-turn movement at B is 100 ft. Movements can be better understood by following the arrow markings in the figure. The NB and SB traffic movements are exactly similar to the corresponding movements at a conventional intersection, with one left-turn lane, one through lane, and one through+right-turn lane. No dedicated right-turn lanes are provided for NB and SB traffic; also no merging lane for EB and WB right-turn movements are necessary. The length of left-turn lane is 450 ft.

The conventional intersection that is compared with the DXI has the following design. There is only one signalized intersection in this case. For EB and WB traffic there are two through lanes, one dedicated left-turn lane and one dedicated right-turn lane. However, there is no merge lane for the right-turn movements from the NB and SB traffic. For NB and SB traffic there are two through lanes, one dedicated left-turn lane, and there is no dedicated right-turn lane (right turn movements share the lane with through movements).

Diverging Diamond Interchange (DDI)

Figure 3 shows the layout of the Diverging Diamond Interchange design. There are two on-ramps and two off-ramps that connect the crossroad and the freeway. The off-ramps have two left-turn lanes and one right-turn lane. One left-turn lane and one right-turn lane lead to the on-ramp. Distance between the two terminals (and crossovers) is 500 ft. The arterial has one through lane, one through+left-turn lane, and one dedicated right-turn lane. Movements can be better understood by following the arrow markings in the figure. Two signalized intersections (A and B) are situated at the two crossover locations. Radii of the curves are same as the radii for DXI.

In rural high-speed environments the nature of this directional crossing of through flows may be hazardous. A suggested forgiving design could provide curved approaches to motivate speed reduction by heightening drivers' awareness. In addition, the directional crossings are made more perpendicular and occupy shorter crossing distances (see Figure 3(b)).

The conventional diamond interchange that is compared with the DDI has the following design. (see Figure 4) On-ramps and off-ramps are exactly the same as DDI, but there is a change in the number of lanes on the arterial. It has two through lanes, one dedicated left-turn lane, and one dedicated right-turn lane. Clearly, the section between the ramps needs more right-of-way as compared to the DDI (two extra left-turn lanes). There are two signals at A and B, and the distance between ramps is also 500 ft.

ANALYSIS METHODOLOGY

Analysis of these innovative designs is done using traffic simulation. Simulation software used for the analysis is VISSIM, a microscopic time step based simulation model.

Analysis of DXI

The CAD design shown in Figure 2 is used as a background in VISSIM and the links are drawn on top of the background. The desired speeds, vehicle classes, priority rules are defined, and signal heads are placed on the links. The DXI design is tested for four different traffic scenarios – peak volume, high volume, medium volume, and low volume. The desired speed for through movements ranges between 36 mph to 42 mph for cars and 30 mph to 36 mph for trucks, for the turn movements the speed ranges from 15 mph to 18 mph for cars and 12 mph to 15 mph for trucks.

Traffic volumes in each direction are shown in Table 1 (peak volumes are obtained from an existing conventional intersection site in Virginia). Signal phasing scheme is shown in Figure 5. Seven phases provide for all movements, three at the main intersection and two each at the two crossovers although they basically operate within three phases. North bound left-turners (phase 3) and south bound left-turners (phase2) go and store in the link until phase 7 and phase 5 turn green respectively. Cycle length of 79 seconds and signal timing shown in Table 1, are the result of numerous trials. The amber time interval used is 3 sec, and the all-red interval is 3 sec at the end of every phase.

Performance criteria for the intersection design include: average delay time per vehicle, average stop time per vehicle, average number of stops per vehicle, average queue length, and maximum queue length. After analyzing these four traffic scenarios, capacity is estimated based on two criteria – level of service and model throughput. When the input volumes are so high that they result in LOS F for the intersection or the model throughput is less than the input volume (less by 100 vph) then we conclude that capacity is reached (see Table 3). Duration of simulation is one hour and the traffic arrivals are Poisson with exponentially distributed headways.

After determining the capacity for the DXI design, the next step is to compare the results obtained with the conventional intersection. A conventional four-legged intersection is analyzed in VISSIM for the same four scenarios and same performance measures. The optimal signal setting for each traffic scenario is obtained from signal optimization software, TRANSYT-7F.

Pedestrian movement is simulated in VISSIM, pedestrian volume of 75 peds/hr is assumed on each approach (Eastbound, Southbound, Westbound, and Northbound) and as there are three possible directions in which each of these volumes can be assigned, the directional volumes are equal to 25 peds/hr (e.g. pedestrian trips generated at South approach is 75 peds/hr, the volume of trips towards East, West, and North is 25 peds/hr each).

Analysis of DDI

Two different designs of DDI are analyzed - a) 4-lane DDI in which the total number of lanes in the east-west direction is four, and b) 6-lane DDI in which there are 6 lanes in the east-west direction. For the first design, five different traffic flow scenarios are considered (hypothetical) including one low, one medium, and three high flows. Performance of the DDI is measured for high flows beyond the capacity of conventional diamond (see Table 4). For the second design, six traffic flow scenarios are considered (see Table 5). Finally, capacities of DDI are estimated for both designs.

Signal phasing scheme used for the DDI is shown in Figure 6. At the left-side ramp terminal, during phase 1, eastbound through movements and southbound lefts are allowed to crossover, and during phase 2, westbound through movements are allowed to crossover. At the right-side ramp terminal, during phase 3, east bound through movements are given green, and during phase 4, westbound through movements, and northbound rights are given green. Phases 5 and 6 are for left-turn movements from the ramp onto the arterial. These left-turners go and store in the link till phase 2 and phase 3 are given green respectively. In this way we can make efficient use of the intersection design. Phase 5 and phase 2 overlap, as there is no conflict between these two movements. In the same way phase 6 overlaps with phase 3. Signal timing shown in Figure 6 is obtained as a result of several trials. For the given phasing sequence, the cycle length of 70 sec is optimal for lower to medium flows, and a cycle length of 100 sec gives best results for higher flows. The amber time used is 3 sec, and the all-red period is 2 sec at the end of every phase. Overall, the signal operates under two main phases.

Capacity of the DDI design is estimated based on the same two criteria mentioned for the DXI design. Results obtained for DDI are compared with the results of conventional diamond interchange. Signal design and optimal signal setting for the conventional diamond interchange is obtained from the PASSER III software.

Pedestrian movements are also simulated in VISSIM for a 4-lane DDI (see Figure 7). Also shown in Figure 7, are the phasing scheme and signal-timing plan that could be adopted to include the pedestrians. The eastbound through traffic moves in phase 1, westbound traffic moves in phase 2, traffic on southbound off ramps have phase 8 for right turns and phase 9 for left turns. Eastbound right-turn traffic moves during phase 1 itself, and the westbound left-turn traffic moves during phase 2. Pedestrian volume of 75 peds/hr is assumed on each approach (Eastbound, Southbound, Westbound, and Northbound); as there are three possible directions in which each of these volumes can be assigned, the directional volumes are equal to 25 peds/hr. (e.g. pedestrian trips generated at South approach is 75 peds/hr, the volume of trips towards East, West, and North is 25 peds/hr each). Walking speed of the pedestrians is assumed to be 4 ft/sec.

RESULTS

Results of the traffic simulation are shown in Tables 1, 2, 3, 4, 5, 6, and 7. Table 1 shows the comparison of traffic performance of DXI with that of conventional intersection. At lower and medium volumes, the performance is almost identical for both designs. However, for higher volumes the performance of DXI is noticeably better than the conventional design. For the conventional design, the model throughput is about 1000 veh/hr lower than the input flow, while for the DXI design the input flow and model throughput are almost similar (difference of about 100 veh/hr). The most important observation is that of the average delay per vehicle. For peak volumes, the delay for conventional design is 220 sec/veh, while it is 86 sec/veh for the DXI. It is also noted that the number of stops, average stop time per vehicle, average queue, and maximum queue length are lower for the DXI when compared with the results of the conventional design.

Traffic performance in the presence of pedestrians is studied for DXI and the results are shown in Table 2. We can see that in spite of the inclusion of pedestrian phase into the signal setting, the performance of DXI is still better than the conventional intersection at high volumes. In Table 2, pedestrian performance is shown for two different types of crossings, one adjacent crossing and diagonal crossing. Adjacent crossing is crossing a single approach, whereas the diagonal crossing would be crossing two approaches at the intersection (e.g. NE-SW). Apart from the standard performance measures such as average delay per person, average stop time per person, etc, we also consider 'average delay per person per stop' which is the ratio of average delay per person and the average number of stops for that crossing. This measure gives an indication if the pedestrians are getting frustrated waiting for the signal and possibly disobeying the signals.

Capacities are estimated for both designs for all signalized movements and the results are summarized in Table 3. Right-turn movements are not included as there are no right-turn signals and all of them are free right-turns. From the results, the main contrasting difference between the capacities of these designs is for left-turns (S-W and N-E). Capacity of the left-turns in the DXI design is more than twice that of the conventional design. This finding suggests that DXI is very suitable at places where there are heavy left-turn movements.

Results for the 4-lane DDI design are shown in Table 4. Performances for lower and medium volumes are identical in both designs (DDI and conventional diamond). However, results for higher volumes show that the conventional diamond has lower model throughput, higher average delay per vehicle, higher stop time, and longer queues as compared to the results of DDI.

The maximum off-ramp flows for the DDI design (700 vphpl) are greater than the corresponding flows in the conventional diamond (390 vphpl) (see Table 6). When off-ramp flows are set to 390 vphpl, for a DDI, the capacity of the cross-road increased by 100 vphpl.

Results for the 6-lane DDI design are shown in Table 5. Apart from the three traffic scenarios discussed earlier, three very high volume scenarios are analyzed. Capacity of each of the three designs (4-lane DDI, 6-lane DDI, and conventional diamond) is shown in Table 6. Capacity of the northbound left-turns, southbound left-turns, eastbound through, eastbound left, westbound through, and westbound left are shown. The DDI design does not have any exclusive left-turn lane unlike the conventional diamond design, and the left-turners share the lane with the through movements. Once again, the big difference between the results of DDI and the conventional diamond relates to the capacity of left-turn movements; capacity of DDI being twice that of the conventional diamond. Capacity of eastbound and westbound left-turns and off-ramp left-turns for the DDI is almost twice that of the conventional diamond.

Pedestrian performance in a 4-lane DDI is shown in Table 7. For crossing the intersection, average walk time is 39 sec and average delay is 35.5 sec/ped. In the table, two LOS criteria are shown - 'average delay' and 'average delay per stop', both expressed in sec/ped.

In our research, we assumed a ramp terminals offset of about 500 ft; however, the DDI design also works for shorter offsets. When the offset was reduced from 500 ft to 300 ft, for the same signal setting (cycle length of 100 s), the capacity of northbound and southbound left turns (off ramps) were lowered by 200 vphpl for the 6-lane design case. Capacity of all other movements remained unchanged. For a shorter cycle length of 80 s, the capacity of the off-ramp left turns decreased by only 100 vphpl but the capacity of through traffic reduced by 75 vphpl approximately. In any case, performance of the DDI design is still better than the corresponding conventional diamond design.

Figure 8 shows a photograph of DDI type design near Versailles, France, that has been in operation for more than 25 years. In the last 5 years, 11 light injury crashes were recorded. For a comparable conventional diamond interchange in the USA, expected number of injury/fatality crashes over 5 years is between 21 and 23 incidents. Expected number of crashes is derived from prediction models of intersection (and intersection related) crashes at ramp terminals and cross street of diamond interchanges, in Washington State (*3*).

CONCLUSIONS

In this paper, two novel intersection/interchange designs were analyzed and compared with conventional designs. The following conclusions can be made from the analysis and results:

DXI

- For higher traffic volumes, the DXI design has better performance and offers lower delays (less than 60%), lesser number of stops, lower stop time, and shorter queue lengths as compared to the performance of the conventional design. For lower volumes, performances of DXI and conventional intersection are similar.
- Capacity of the through movements is same for both the designs. However, the capacity of left-turn movements (Northbound and Southbound) for the DXI design is twice that of the conventional design. This suggests that the DXI may be suitable to situations where there are heavy left-turn movements in two opposing directions.
- Pedestrian performance is measured in terms of average delay per person per stop. DXI offers a LOS C in terms of this measure. However, the number of stops for crossing is higher as compared to the corresponding number of stops at a conventional intersection.
- This design has two additional signals where through vehicle crisscross making the intersection more complex and with questionable safety.

DDI

- Two cases of DDI were studied: 4-lanes and 6-lanes. For higher traffic volumes, the DDI design has better performance and offers lower delays, lesser number of stops, lower stop time and shorter queue lengths as compared to the performance of the conventional design. For lower volumes, performances of DDI and conventional intersection are similar.
- Capacity for all signalized movements is higher for the DDI as compared to the conventional diamond. Especially, capacity of the left-turn movements is twice that of the corresponding left-turn capacity of the conventional diamond. The DDI design is very superior to the conventional diamond design as exclusive left-turn lanes are not necessary for the DDI.
- Conventional diamond design comparable to the 4-lane DDI consists of 6-lanes on the bridge section (2 through and 1 left-turn in each direction, E-W and W-E). When higher capacity is needed, it would be a good application to convert to a 6-lane DDI instead of pursuing the costly option of widening bridges and approaches with dual left lanes in each direction.
- While the DDI design does not allow through movements from off- to on-ramps, it allows u-turn movements with fewer conflicts than at a conventional diamond interchange.
- For the considered pedestrian facility, the average LOS is D and the comparable LOS per stop is C. On an average, pedestrians have to make 1.6 stops per crossing.

RECOMMENDATION FOR FUTURE RESEARCH

Safety aspects of the suggested designs need to be studied in more detail. Surrogate safety assessment model is currently under development at FHWA, and after its completion we expect to use it to compare the safety aspects of DDI, DXI, and conventional diamond. The proposed safety model aims at extracting the safety features from traffic simulation models (VISSIM, AIMSUN, and TEXAS Model) by analyzing the trajectory of vehicles and estimating their proximity. Another recommendation would be to compare the proposed DDI performance with the performance of a single point diamond interchange. Finally, the impact of the design on abutting properties needs to be evaluated as more research is done on these types of designs. There could be some access limitations due to the potential length of the crossed traffic directions. Access may have to be limited or prohibited within the section that is crossed to the left side of the road.

ACKNOWLEDGMENT

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LIST OF TABLES AND FIGURES

TABLE 1 Double Crossover Intersection (DXI) vs. Conventional Intersection – Traffic Scenarios and Performance Results (without pedestrians)

Traffic Scenario	Northbound (veh/hr)			Southbound (veh/hr)			Eastbound (veh/hr)			Westbound (veh/hr)			Total Flow (veh/hr)
	L	T	R	L	T	R	L	T	R	L	T	R	
Peak	348	792	96	400	1150	144	180	842	552	100	1024	124	5752
High	348	792	96	350	1100	100	150	800	500	100	950	124	5410
Medium	175	400	50	200	600	70	90	420	275	50	500	60	2890
Low	90	200	25	100	300	35	45	210	140	25	250	30	1450

Traffic Scenario	Input Flow (veh/hr)	Model Throughput (veh/hr)		Delay Time (sec/veh)		Stop Time (sec/veh)		Number of Stops		Average Queue (ft)		Maximum Queue (ft)	
		DXI	Conv	DXI	Conv	DXI	Conv	DXI	Conv	DXI	Conv	DXI	Conv
Peak	5752	5630	4538	86	220	51	143	2.4	4.2	242	647.5	1057.1	1386.4
High	5410	5365	4540	45	174	29	105	1.2	3.4	63	490.0	392.2	1371.0
Medium	2890	2854	2856	26	36	19	29	0.8	0.7	17	46.4	166.6	238.2
Low	1450	1430	1434	25	23	19	18	0.8	0.6	8	14.0	81.1	100.7

Conv = Conventional   L = Left, T = Through, R = Right

TABLE 2 Double Crossover Intersection (DXI) – Traffic Scenarios and Performance Results (with pedestrians)

Traffic Scenario	Flows (veh/hr)		Delay Time (sec/veh)	Stop Time (sec/veh)	Number of Stops	Maximum Queue (ft)
	Input	Actual				
Peak	5752	5630	149	65	3.6	1673.7
High	5410	5365	86	43	2.3	1000
Medium	2890	2854	30	21	0.9	217.3
Low	1450	1430	27	19	0.8	100.2

Pedestrians	Delay Time (sec/person)	Stop Time (sec/person)	Number of Stops	Average Delay per stop (sec/person)
Diagonal Crossing (e.g. S-W)	98	93	4	24
Adjacent Crossing (e.g. S-N)	63	59	2	31

TABLE 3 Capacity of Conventional and DXI designs

	E-W	W-E	E-S	W-N	S-W	S-N	N-E	N-S
Conventional (veh/hr)	600	450	100	100	170	575	175	575
DXI (veh/hr)	550	450	100	150	350	550	375	575

TABLE 4 Diverging Diamond Interchange (4-lane) vs. Conventional Diamond Interchange – Traffic Scenarios and Performance Results

Traffic Scenario	Northbound (veh/hr) *off-ramp*			Southbound (veh/hr) *off-ramp*			Eastbound (veh/hr)			Westbound (veh/hr)			Total Flow (veh/hr)
	L	T	R	L	T	R	L	T	R	L	T	R	
High 3	750	0	450	750	0	450	450	850	550	450	850	550	6100
High 2	700	0	400	700	0	400	400	800	500	400	800	500	5600
High 1	650	0	350	650	0	350	350	750	450	350	750	450	5100
Medium	400	0	200	400	0	200	200	500	300	200	500	300	3200
Low	200	0	100	200	0	100	100	300	150	100	300	150	1700

Traffic Scenario	Input Flow (veh/hr)	Model Throughput (veh/hr)		Delay Time (sec/veh)		Stop Time (sec/veh)		Number of Stops		Maximum Queue (ft)	
		DDI	Conv	DDI	Conv	DDI	Conv	DDI	Conv	DDI	Conv
High 3	6100	5800	5228	62	105	32	55	1.4	2.4	1191	1665
High 2	5600	5380	5187	40	91	24	46	0.9	2.3	1000	1170
High 1	5100	4912	4869	32	66	20	35	0.8	1.8	482	1108
Medium	3200	3074	3104	20	26	12	13	0.7	0.9	239	262
Low	1700	1631	1631	17	20	11	11	0.6	0.8	123	120

Conv = Conventional L = Left, T = Through, R = Right

TABLE 5 Diverging Diamond Interchange (6-lane) - Traffic Scenarios and Performance Results

Traffic Scenario	Northbound (veh/hr) *off-ramp*			Southbound (veh/hr) *off-ramp*			Eastbound (veh/hr)			Westbound (veh/hr)			Total Flow (veh/hr)
	L	T	R	L	T	R	L	T	R	L	T	R	
V.High-3	1000	0	700	1000	0	700	700	1100	800	700	1100	800	8600
V.High-2	800	0	500	800	0	500	500	900	600	500	900	600	6600
V.High-1	700	0	400	700	0	400	400	800	500	400	800	500	5600
High	650	0	350	650	0	350	350	750	450	350	750	450	5100
Medium	400	0	200	400	0	200	200	500	300	200	500	300	3200
Low	200	0	100	200	0	100	100	300	150	100	300	150	1700

Traffic Scenario	Input Flow (veh/hr)	Model Throughput (veh/hr)	Delay Time (sec/veh)	Stop Time (sec/veh)	Number of Stops (per veh)	Maximum Queue (ft)
V.High-3	8600	8200	58	28	1.1	785
V.High-2	6600	6500	32	19	0.8	450
V.High-1	5600	5500	28	18	0.7	421
High	5100	5040	27	18	0.7	305
Medium	3200	3170	18	11	0.6	186
Low	1700	1690	16	11	0.6	121

L = Left, T = Through, R = Right

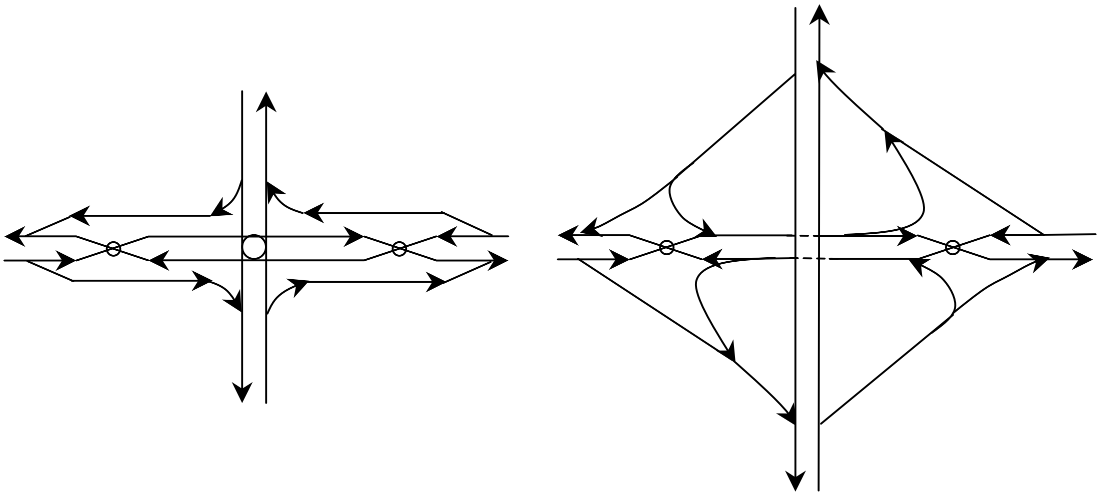
TABLE 6 Capacity of Conventional and DDI designs

Capacity	Northbound (veh/hr) *off-ramp*	Southbound (veh/hr) *off-ramp*	Eastbound (veh/hr)		Westbound (veh/hr)	
	L	L	L	T	L	T
Diverging Diamond (4-Lanes)	600	600	600(L/T)	600	600(L/T)	600
Diverging Diamond (6-Lanes)	700	700	600(L/T)	600	600(L/T)	600
Conventional Diamond	390	390	330	600	330	600

L = Left, T = Through, R = Right, L/T = Left and Through

TABLE 7 Pedestrian performance for a 4-lane DDI

Movement	Average Walk Time (sec)	Average Delay (sec/ped)	Pedestrian LOS	Average Number of Stops	Average Delay per Stop (sec/ped)	Pedestrian LOS
SW-SE	32	24.6	C	1.4	17.6	B
SE-SW	32	22.9	C	1.2	19.1	B
NW-NE	46	25.0	C	1.2	20.8	C
NE-NW	31	26.7	C	1.5	17.8	B
SW-NW	48	31.7	D	1.5	21.1	C
NW-SW	40	53.7	E	2.0	26.9	C
SE-NE	33	32.8	D	1.7	19.3	B
NE-SE	50	66.1	F	1.9	34.8	D
All	39	35.5	D	1.6	25.0	C



(a)

(b)

FIGURE 1 (a) Synchronized Split-Phasing Intersection, and (b) Diverging Diamond Interchange (after Chlewicki (*2*)).

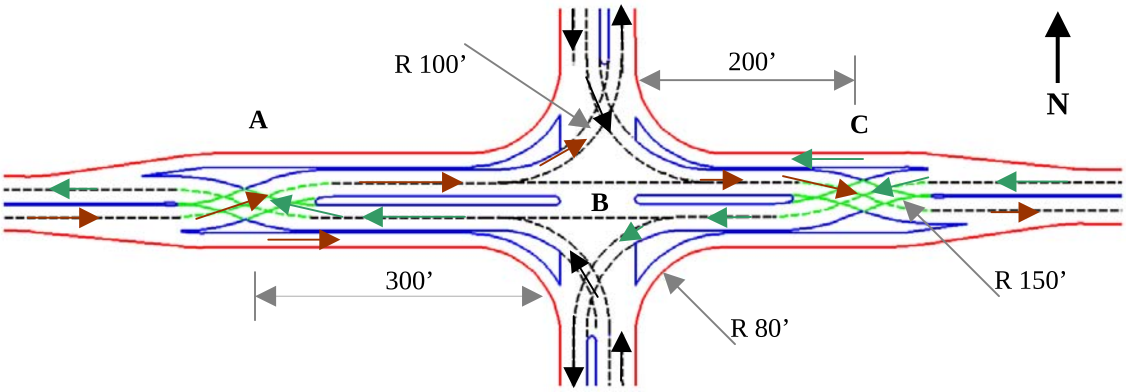
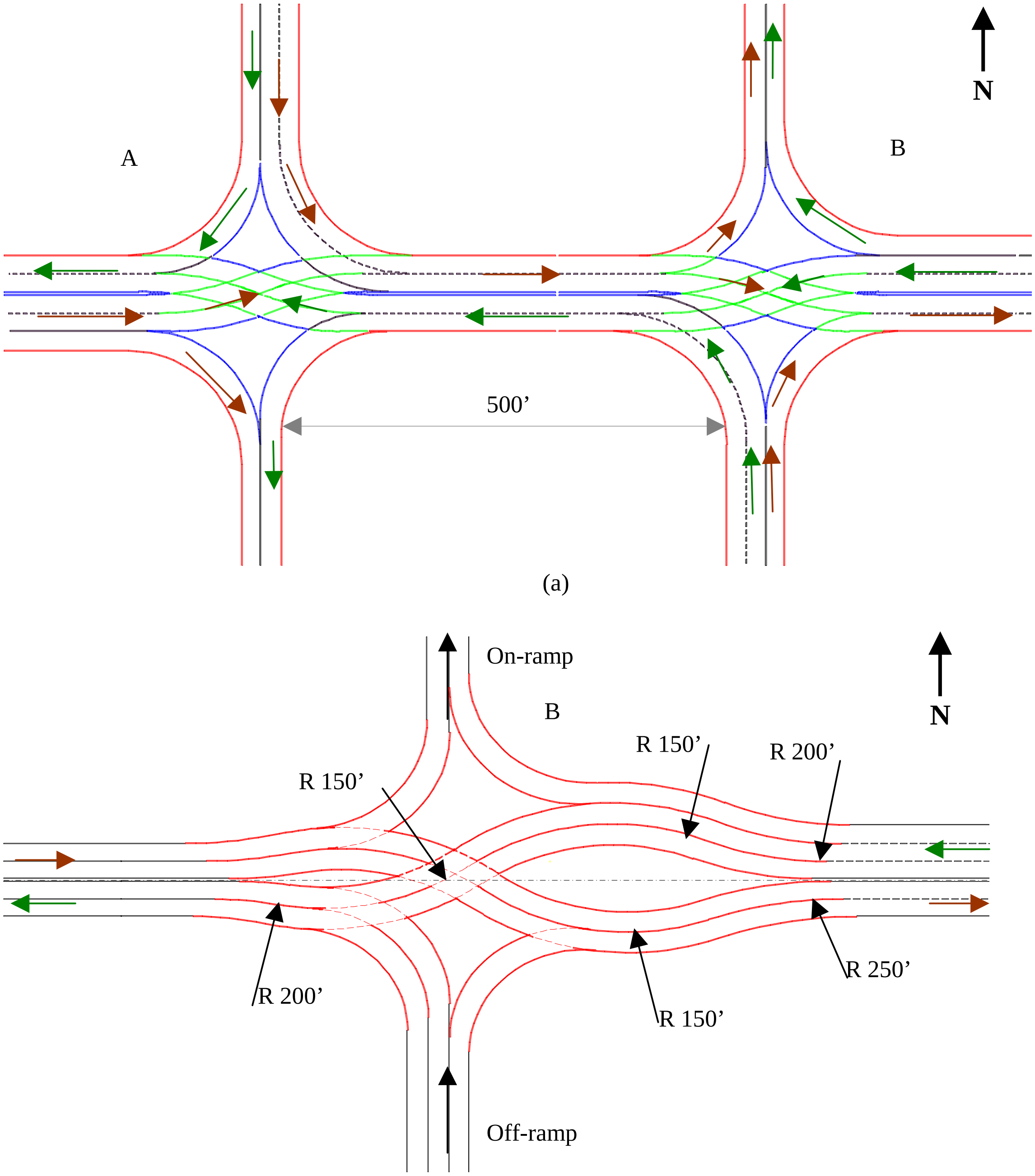


FIGURE 2 Double Crossover Intersection (DXI) layout.



(a)

(b)

FIGURE 3 (a) Typical layout of a Diverging Diamond Interchange layout; (b) Proposed geometric- - improvements at the right side ramp terminal

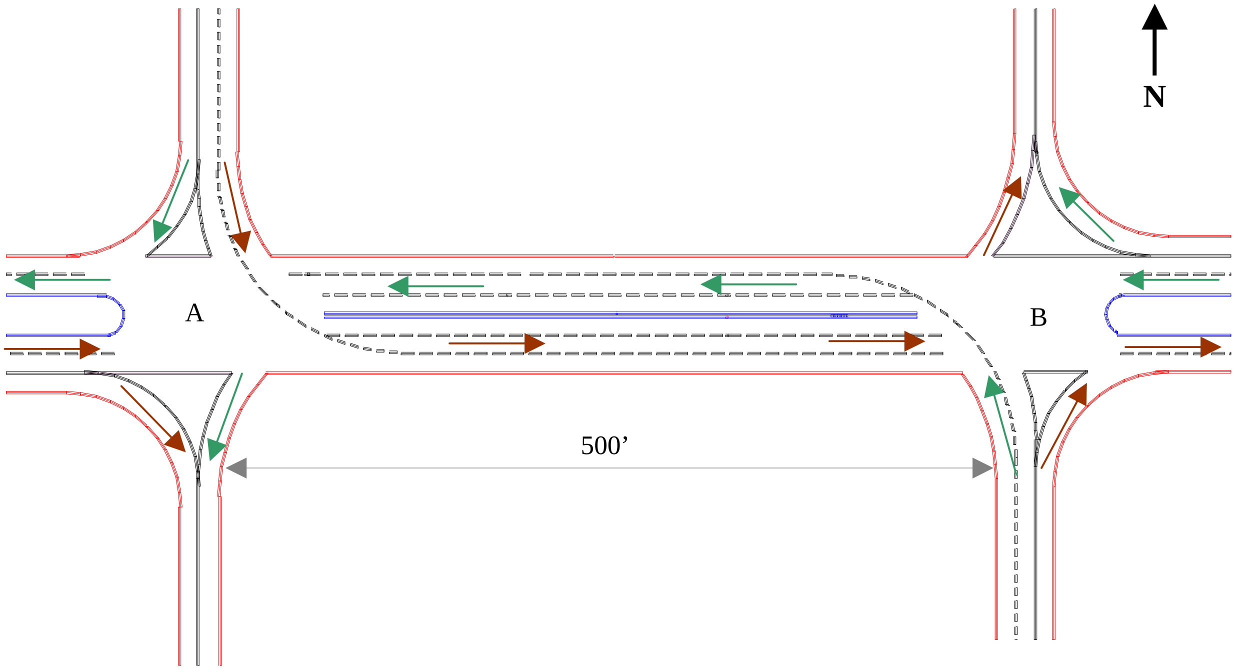
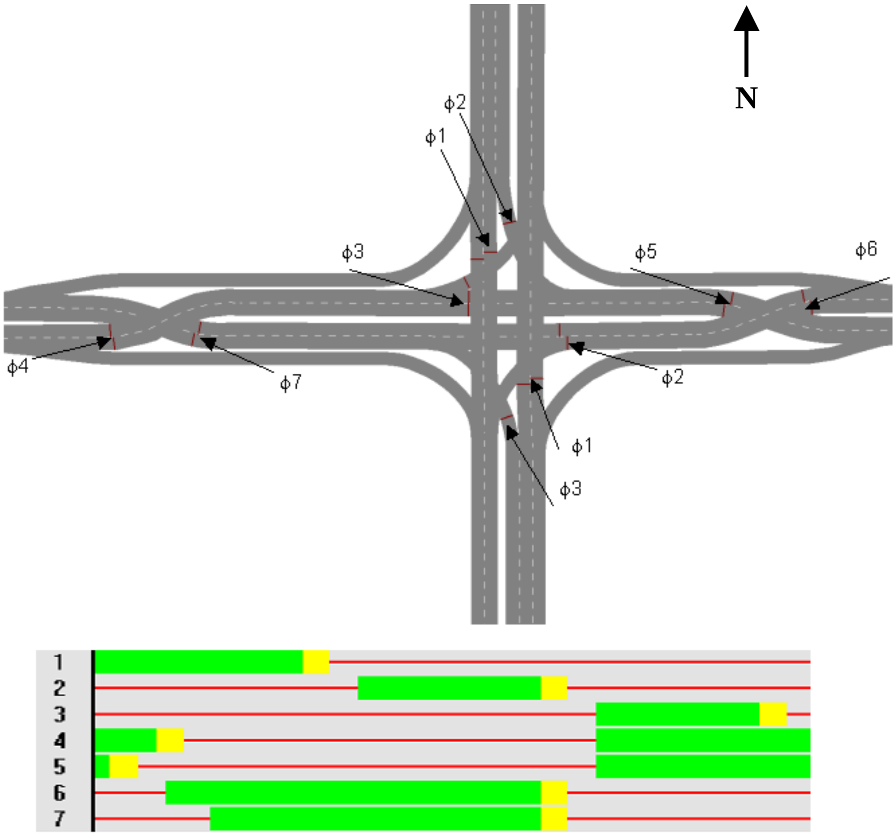
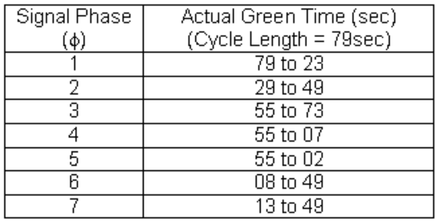


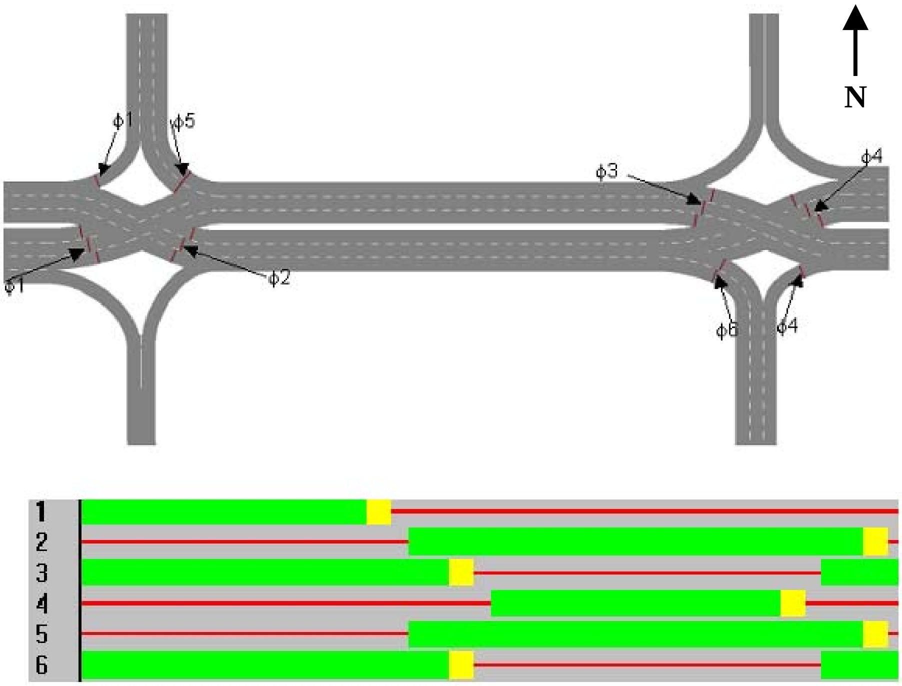
FIGURE 4 Conventional Diamond Interchange layout.

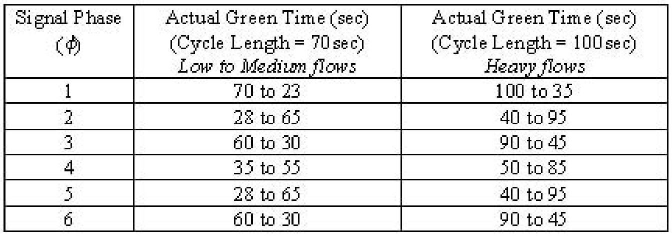




Signal Phase (ϕ)	Actual Green Time (sec) (Cycle Length = 79sec)
1	79 to 23
2	29 to 49
3	55 to 73
4	55 to 07
5	55 to 02
6	08 to 49
7	13 to 49

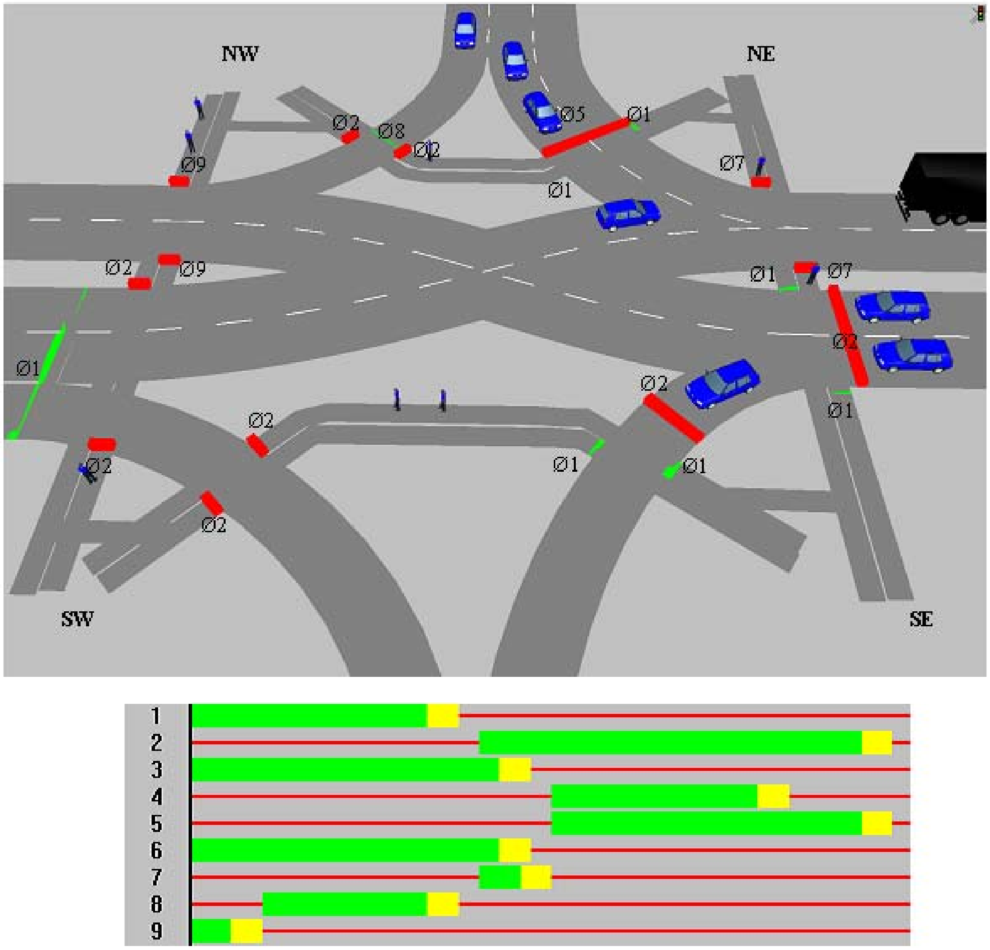
FIGURE 5 Signal setting for DXI.





Signal Phase (ϕ)	Actual Green Time (sec) (Cycle Length = 70 sec) *Low to Medium flows*	Actual Green Time (sec) (Cycle Length = 100 sec) *Heavy flows*
1	70 to 23	100 to 35
2	28 to 65	40 to 95
3	60 to 30	90 to 45
4	35 to 55	50 to 85
5	28 to 65	40 to 95
6	60 to 30	90 to 45

FIGURE 6 Signal setting for DDI.



Signal Phase (Ø)	Actual Green Time (sec) Cycle Length (70sec)
1	70 to 23
2	28 to 65
3	70 to 30
4	35 to 55
5	35 to 65
6	70 to 30
7	28 to 32
8	7 to 23
9	70 to 4

FIGURE 7 Signal setting for 4-lane DDI with pedestrian movements at the left-side ramp terminal.

FIGURE 8 Interchange at the intersection of A 13 and RD 182 near Versailles, France. (Image purchased from GlobeXplorer^{TM}.)