

A Comparative Analysis of Diverging Diamond Interchange Operations

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ABSTRACT

Travel demand is steadily increasing all over the country. This is pushing the limits of our existing roadway infrastructure. The need to provide additional capacity is constantly at odds with the potential impacts that transportation improvements have on existing developments. The diverging diamond interchange (DDI) is an innovative new concept being pursued as an alternative interchange type that may provide a significant increase in capacity while actually reducing the bridge size requirements. This paper will discuss the operational benefits of the DDI in comparison to a diamond and a single point urban interchange.

The DDI appears to be an option that can greatly improve operations and capacity at the ramp terminal intersections. The operations of the DDI will be compared to the operations of other interchange types which will also allow for a planning-level assessment of the differences in the interchange footprints.

This interchange concept is based on a standard diamond interchange with the key difference being a shift in the crossroad traffic in the interchange. Traffic on the crossroad crosses paths twice as traffic is shifted to the left side of oncoming traffic allowing left turn movements to occur without impeding oncoming traffic or yielding to it.

The paper is intended to introduce engineers to the operational benefits of the DDI versus conventional interchange concepts and to identify when and where the greatest amount of benefit may be realized.

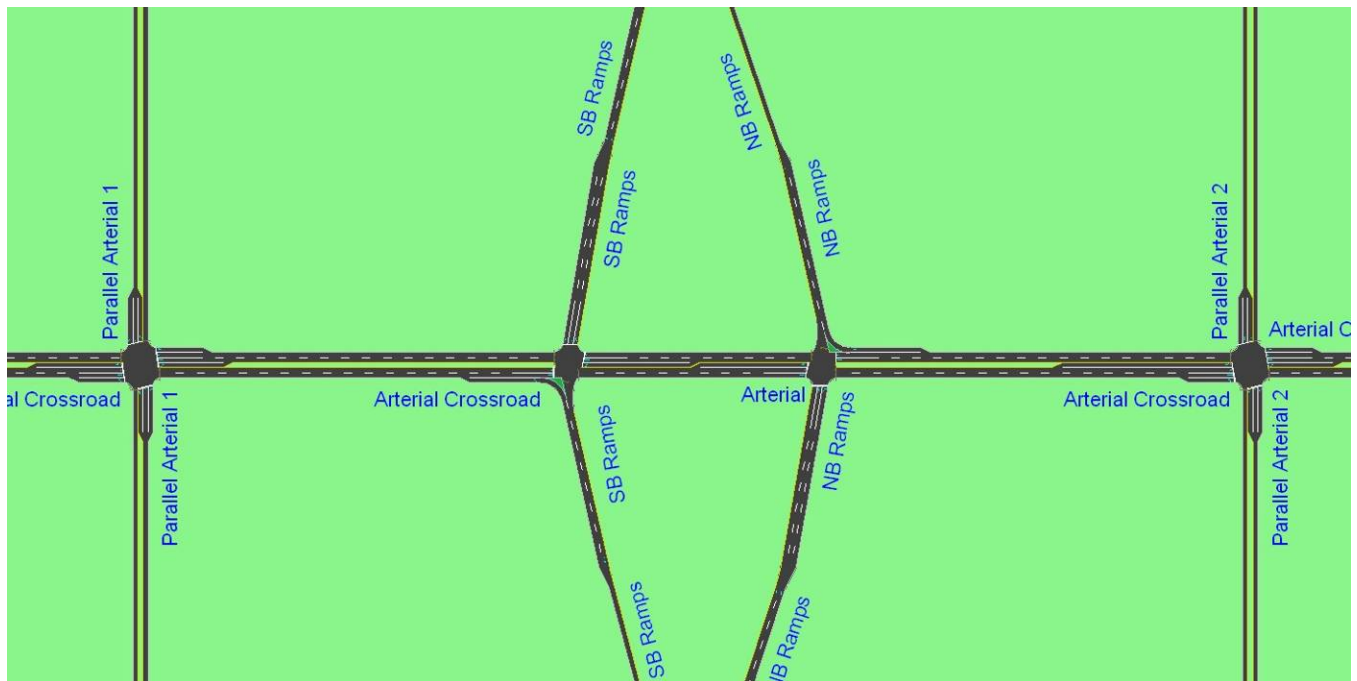
General Interchange Characteristics

Three interchange types were chosen for comparison in this paper: Diamond, Single Point Urban Interchange (SPUI), and the Diverging Diamond Interchange (DDI). The interchange types have different characteristics relating to capacity, signal phasing, conflict points, construction cost, structural requirements, driver familiarity and pedestrian considerations. The focus of this paper is to compare operations of the interchanges using microscopic simulation tools.

Diamond Interchange

A layout of a diamond interchange is shown in Figure 1. The diamond interchange has two signalized intersections to serve ramp terminal and crossroad movements. Signal timing plans are developed to minimize the number of vehicles stored between the two signals.

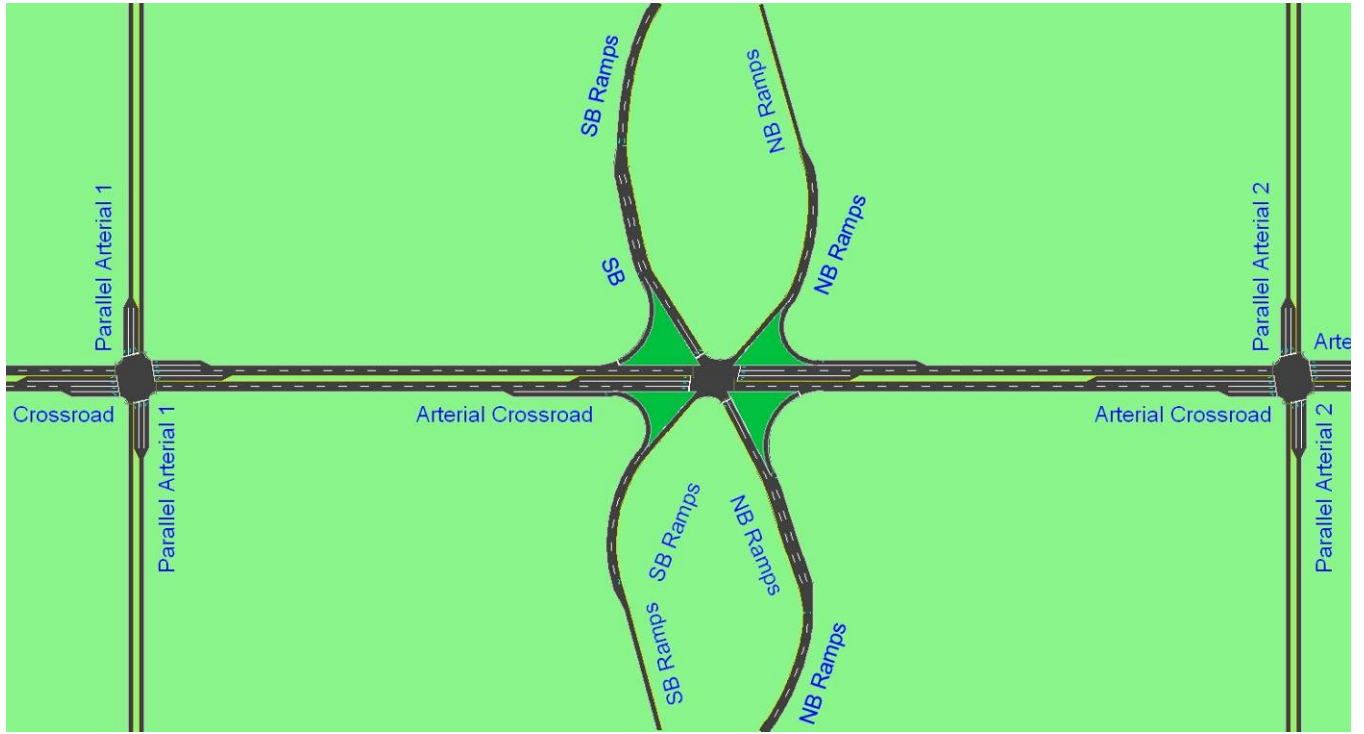
Figure 1 – Diamond Configuration



Single Point Urban Interchange (SPUI)

A conceptual layout of a SPUI interchange type is shown in Figure 2. The SPUI involves a single signalized intersection for all ramp and crossroad movements. Due to the substantial width of the intersection, clearance interval (yellow plus all-red) requirements of nine to ten seconds per phase are not uncommon for a typical SPUI design. Three phase signal control is commonly used for SPUI's, providing leading left-turn and through movement phasing for the cross street and a phase for the ramp left-turn movements. The right-turn ramp movements can be signal or yield controlled. This movement could also be free if a receiving lane is in place.

Figure 2 – SPUI Configuration



lengths, such that each alternative would have the same network surrounding it. The surrounding street intersections were not evaluated as intersections, but were included to account for platooning and queuing reasons in the comparative analysis.

Synchro was used to develop an optimum timing plan for each scenario. The traffic signals were coded as pre-timed to reduce the variability in results that can occur when simulating semi or fully actuated signal control. Due to the use of single left turns from the arterial crossroad, permitted/protected phasing was used. When using protected only phasing and/or dual-left turns, the operational difference between the DDI and other concepts are increased, however this was not analyzed for this paper. Also, a cycle length of 90 seconds was selected for all scenarios to reduce the number of variables to consider when comparing results. It is recognized that one of the major differences between the interchange concepts is the number of phases required. A diverging diamond interchange only requires two phases per intersection, as there are no left turns to control. This also contributes to a reduction in lost time per phase changeover. Note that it is important to verify that the all-red intervals are coded properly, as lost time is a distinct difference between the concepts, not only in the number of phases, but the amount of lost time due to crossing time required.

Conflict Points

When analyzing a diverging diamond interchange, one of the most intriguing things to look at is the reduction in conflict points. This is not only an operational benefit, but will likely impact the safety aspect of the interchange as well. Table 1 shows a comparison of the three interchange concepts conflict points.

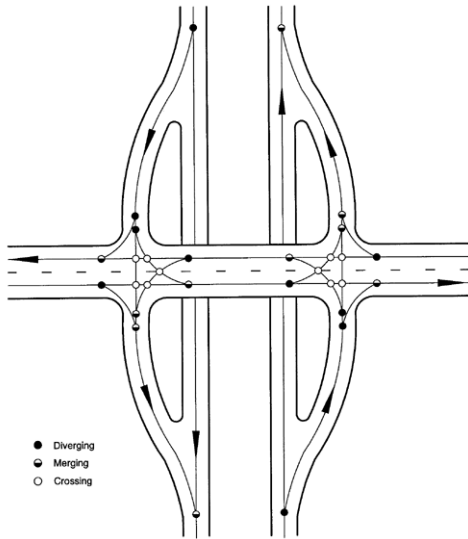
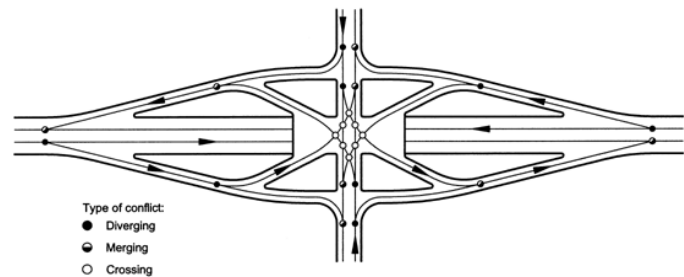


Table 1 – Conflict Points

Type	Diamond	SPUI	DDI
Diverging	10	8	6
Merging	10	8	6
Crossing	10	8	2
Total	30	24	14



The diverging diamond interchange concept has significantly fewer conflict points, and most notably, only has two crossing points. Also it is important to note the number of simultaneous points of conflict, which do not exist in the diverging diamond interchange concept, as any vehicle entering the intersections can only be struck from one direction. When considering operations, this



type of conflict requires significantly less yellow and all red time to control, which means less lost time and more green time and more capacity.

ANALYSIS PROCEDURES AND WORKFLOW

Analysis Tools

The analysis was conducted with three traffic engineering computer programs; Synchro 7, SimTraffic and VISSIM 4.2. The programs are described as follows:

Synchro 7 (Build 007) is a comprehensive network capacity analysis and signal timing software developed by Trafficware. The software is based on the methodology from the most current version of the Highway Capacity Manual and is user friendly. For this paper, Synchro 6.0 (the previous version of Synchro) was utilized to develop portions of the input files for VISSIM for the Diamond, SPUI and DDI alternatives. Additionally, Synchro's signal timing optimization was utilized to develop the signal timing plans, with only minor adjustment by the user.

SimTraffic is a microsimulation tool directly linked to Synchro and is also developed by Trafficware. A direct transfer from Synchro imports all relevant data into the SimTraffic model. The SimTraffic model is a time-based, stochastic simulation of individual vehicles. Comprehensive measures of effectiveness (MOE's) are computed for each vehicle in the model for every time step of model simulation. SimTraffic has the ability to collect system wide measurements, as well as intersection and corridor related statistics.

VISSIM (version 4.2) is a microsimulation tool developed by PTV. The VISSIM model is a time-based, stochastic simulation of individual vehicles. Comprehensive measures of effectiveness (MOE's) are computed for each vehicle in the model for every time step of model simulation. VISSIM has the ability to collect system wide measurements as well as movement, approach, link, route, area, and other MOE possibilities. The software also generates animated graphics, which display street networks, traffic control device indications, and the animated movement of vehicles through the model. These graphics can be displayed in 2-D or 3-D.

Workflow Process

The workflow developed for the analysis was to use SimTraffic to analyze the comparison of the three alternatives under the various traffic volume scenarios. SimTraffic offered a direct transfer from Synchro, which was used to develop signal timings for the alternative comparison. After initial testing it was determined that SimTraffic was limited in how it could accurately simulate the DDI configuration. The software was showing illogical blockages, and it became apparent other software was needed to do a fair comparison. VISSIM seems to have more realistic driver behavior within the intersections. Due to the flexibility in geometry, routing, stop point location and results offered, the alternative comparison was carried forward using VISSIM.

The workflow used to evaluate the DDI and the SPUI interchange with VISSIM was as follows. First, the interchange link-node diagram was coded in Synchro to generate geometry, volume and timing files that can be imported into VISSIM. Synchro could not generate a complete

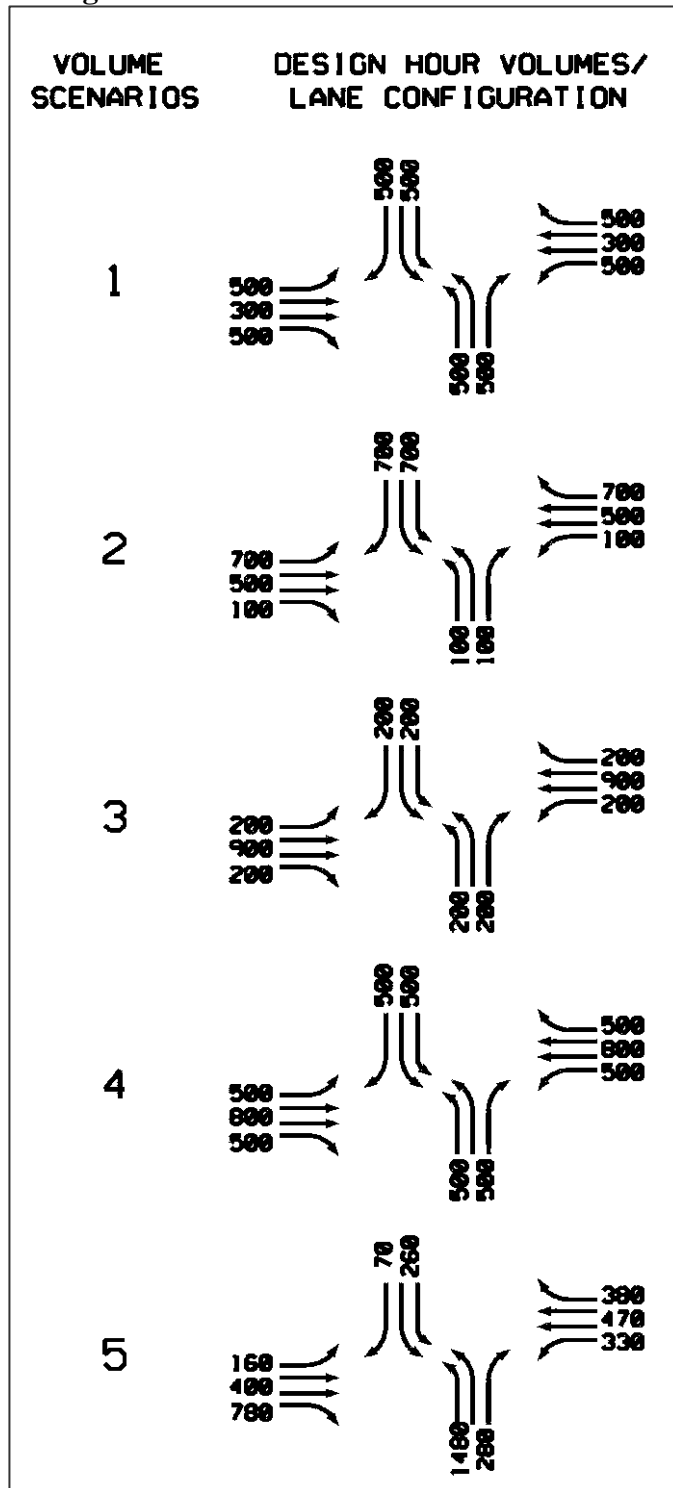
VISSIM network for an intersection with more than four legs, nor can it replicate the complexity of the DDI. Therefore, manual coding within the VISSIM file was necessary from this point on for the DDI and SPUI. The diamond interchange also needed some geometric “clean-up” prior to having a functional VISSIM model. The VISSIM file was edited in all scenarios to add the information that was not converted directly from Synchro (i.e. redefine lane geometry, lane alignments and turning volumes). Left-turn speeds were adjusted in VISSIM from the default settings to a faster speed to account for increased left-turn speeds for the SPUI layout. Default driver behavior and other calibration parameters were used for each scenario to achieve a more direct comparison between the scenarios.

Once the VISSIM files were complete, visual error checking and volume validation was completed. Seeding times of 15 minutes was used for all scenarios. Once all volumes matched within 5% of the input demand, the VISSIM models were run ten times and MOE data was collected, averaged and processed.

Traffic Volumes

The traffic operations of the three interchange designs were compared for four different volume scenarios in order to get a good understanding of the conditions that affect each of the interchange types. The volume scenarios are detailed in Figure 5. Typically the SPUI configuration is used when there are high volumes, specifically for left-turns, thus dual left-turns

Figure 5 – Traffic Volumes



are frequently designed into this configuration. However, to achieve a better-quality comparison for the volume scenarios for the purposes of the paper, arterial street single left-turns were used for both the diamond and the SPUI configurations. It is understood that under higher volumes scenarios and due to the difficulty of expanding the SPUI and the uncertainty associated with the traffic projections, dual left-turn movements would typically accompany the SPUI configuration. To compare the capacity and delay characteristics of the interchange types, the traffic patterns were varied with high balanced ramp volumes, high unbalanced ramp volumes, heavy arterial volumes, mid-to heavy level overall volumes, and a real-world projected condition (shown as volume scenarios 1 through 5 in Figure 5, respectively.)

In VISSIM, the traffic volume routing was coded as origin-destination (meaning all vehicles entering the network have specific paths) rather than from intersection to intersection. This was done to ensure the correct lane utilization and lane changing. SimTraffic does not have the ability to route vehicles in this manner, however the trips within the diamond configurations were coded such that vehicles would not make “u-turns” within the interchange.

Results

The traffic simulation analysis resulted in numerous traffic measures of effectiveness for the interchange configurations and volume scenarios noted above. The intersection average vehicle control delay and queue lengths are summarized in Table 2, Table 3 and Table 4. Queue lengths included in the table represent the maximum simulated queue lengths (for ten runs) on the ramp and crossroad.

Table 2 – Diamond Intersection Measures of Effectiveness (VISSIM)

Volume Scenario	Average Vehicle Delay (sec/veh)	Queue Lengths (ft)	
		Ramp	Crossroad
1 – East	13.6	686	523
1 – West	13.4	561	606
2 – East	9.5	112	618
2 – West	27.7	834	613
3 – East	7.9	264	229
3 – West	7.7	200	354
4 – East	29.8	799	1058
4 – West	45.1	852	1043
5 – East	24.6	473	425
5 – West	8.3	150	399

The intersection measures of effectiveness are very comparable for the different interchange configurations.

Table 3 – SPUI Intersection Measures of Effectiveness (VISSIM)

Volume Scenario	Average Vehicle Delay (sec/veh)	Queue Lengths (ft)	
		Ramp	Crossroad
1	13.3	254	214
2	22.2	308	488
3	12.7	148	378
4	24.7	762	474
5	19.6	742	276

The DDI configuration increases in value with more volume, especially with the increase of ramp volume. The least beneficial scenario is when the arterial volumes are heavy, and the ramp interchange traffic is lower.

Table 4 – DDI Intersection Measures of Effectiveness (VISSIM)

Volume Scenario	Average Vehicle Delay (sec/veh)	Queue Lengths (ft)	
		Ramp	Crossroad
1 – East	10.5	532	534
1 – West	10.5	397	385
2 – East	9.2	95	440
2 – West	20.6	468	824
3 – East	8.4	205	327
3 – West	8.3	156	237
4 – East	16.3	548	662
4 – West	16.5	570	785
5 – East	19.8	386	369
5 – West	8.8	84	323

COMPARATIVE ASSESSMENT AND CONCLUSIONS

System-wide measures of effectiveness were calculated within SimTraffic and VISSIM to enable direct comparative assessment of the interchange alternatives. Table 4 is a summary of the system-wide average delay and stop statistics in SimTraffic for the first three volume scenarios. The statistics from VISSIM for each of the five previously described volume scenarios are shown in Table 5.

Table 4 – System-Wide Measures of Effectiveness Comparison (SimTraffic)

Volume Scenario	Number of Vehicles Served			Average Delay Time per Vehicle (s)			Average number of Stops per Vehicle		
	Diamond	SPUI	DDI	Diamond	SPUI	DDI	Diamond	SPUI	DDI
1	5459	5767	5784	236.6*	116.8	94.3	2.92	1.66	1.30
2	4923	4739	5339	297.7*	500.0*	98.0	2.52	2.81	1.46
3	4578	4569	4569	58.5	70.5	89.1	1.37	1.35	1.46

* Note – queuing occurred beyond the limits of the network, thus delay numbers are lower than the actual delay for the demand vehicles.

Table 5 – System-Wide Measures of Effectiveness Comparison (VISSIM)

Volume Scenario	Average Delay Time per Vehicle (s)			Total Number of Stops			Average Number of Stops per Vehicle		
	Diamond	SPUI	DDI	Diamond	SPUI	DDI	Diamond	SPUI	DDI
1	42.8	32.9	35.9	7742	5980	6281	1.30	1.00	1.05
2	48.8	40.8	45.4	8073	6702	7241	1.45	1.21	1.30
3	37.1	37.4	36.2	5512	6143	4848	1.17	1.30	1.03
4	76.2	48.1	46.0	15960	9908	9220	2.30	1.41	1.31
5	57.5	46.9	46.1	8639	6812	7231	1.66	1.32	1.39

The results show that the DDI operates better than a standard diamond in all scenarios, despite having fewer lanes in the bridge area. With the operational analysis, the higher the volume, the more benefit the DDI gives over the standard diamond, even when running with fewer lanes and having the diamond having protected-permitted phasing. It was expected in scenario 3 that the

DDI would have worse operations than the other alternatives, due to the heavier through traffic, however, the DDI still outperformed the other scenarios. This is likely due to having less lost time, fewer phases, thus adequate through bands to accommodate the arterial road traffic. The SPUI operates slightly better than the DDI when the traffic volumes are lower. This is due to running the simulation as protected-permitted phasing.

After running tests with protected only phasing and adjusted timing plans; it was determined that the DDI far outperforms the Diamond and the SPUI under all scenarios, even with fewer lanes. Realistically, left turns at ramp terminal intersection with this type of configuration and volume would be operating as protected only in most jurisdictions for safety reasons.

RECOMMENDATIONS FOR FURTHER STUDY

- Perform traffic simulation analysis to compare the operational characteristics for the interchange configurations for a wider range of volume scenarios and geometry (dual-left turn lanes, etc.), particularly in situations approaching capacity with unbalanced crossroad through or ramp left-turn traffic volumes. The DDI can also expand to accommodate a higher through volumes and left turns by adding a free left-turn lane. Compare this to dual left-turns and the resulting right-turn yielding due to the dual lefts.
- Compare the freeway merge operations with different interchange types. Signal timing platooning can affect the traffic flow pattern onto the freeway at the merge points. The comparison should be done comparing dual left-turns from a more standard configuration compared to the DDI.
- Compare operations of the interchange configurations with ramp metering.
- Provide more research into operational and safety characteristics of the diverging diamond interchange in real-world applications.
- Compare the diverging diamond interchange concept to other interchange configurations, including partial clover and diamond interchanges with roundabout ramp terminal intersections.
- Utilize traffic simulation to evaluate the operations of the interchange configurations considering the effects of bicycles and pedestrians.

REFERENCES

1. VISSIM 4.2 Manual, Developed by PTV America, Inc., Corvallis, OR.
2. Synchro 7.0 User Guide (on-line), Developed by Trafficware Corporation, 1009B Solano Ave, Albany, CA.
3. Signalized Intersections: Informational Guide, Publication No. FHWA-HRT-04-091, Federal Highway Administration, Washington, DC, 2004.
4. Traffic Models Overview Handbook, Report No. FHWA-SA-93-050, Federal Highway Administration, Washington, DC, 1993.
5. Selinger, Matt and Sharp, Will. Comparison of SPUI & TDUI Interchange Alternatives with Computer Simulation Modeling. ITE, 2000.
6. Leisch, Joel P., Thomas Urbanik II, and James P. Oxley. A Comparison of Two Diamond Interchange Forms in Urban Areas. *ITE Journal*, November 1989.

7. Bonneson, J. A. Study of Headway and Lost Time at Single-Point Urban Interchanges. *Transportation Research Record 1365*, TRB, National Research Council, Washington, DC, 1992.
8. Fowler, Brian C., An Operational Comparison of the Single-Point Urban and Tight-Diamond Interchanges. *ITE Journal*, April 1993.

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