SIGNAL TIMING STRATEGIES FOR GEORGIA'S FIRST IN-HOUSE DESIGNED DDI

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ABSTRACT

After opening three diverging diamond interchanges in the Greater Atlanta area, the Georgia Department of Transportation is planning its first in-house designed diverging diamond interchange at I-285 and Camp Creek Parkway, a diamond interchange with busy signalized intersections adjacent to west ramp. Camp Creek Parkway is a 4-lane principle arterial with 75,500 ADT at the interchange location; it widens to 6-lane at the bridge with 2 through lanes and one left turn lane in each direction. The freeway underneath carries 147,000 ADT. The Hartsfield Jackson Atlanta International Airport is 6.3 miles to the east that connects directly to Camp Creek Parkway. The interchange's northwest corner is a shopping center with big-box stores like Target and Lowe's; its southwest corner has one gasoline station, two hotels, three restaurants, and two large warehouses that park many tracker-trailers. The current afternoon peak hour traffic demands at the four signalized intersections are 5,400 VPH, 5,500 (ramp) VPH, 4,000 (ramp) VPH, and 2,900 VPH, respectively. At present, the ramp terminals are congested, and the adjacent signal intersection to the west, which serves the shopping center and two warehouses, is very congested. Preliminary analysis shows that if the diamond interchange is converted into a diverging diamond interchange, congestion at the nearby signal intersection will get worse, and the queue may spill back to the new interchange and constrain its capacity. Upon request, the researchers examined the traffic demand patterns at and near the interchange, and developed several improvement options and signal timing strategies, including novel treatments at the adjacent signal intersections, that can relieve corridor congestion and enable the diverging diamond interchange to function at maximum capacity.

Keywords: Diverging diamond interchange, alternative intersection, quadrant road intersection, continuous flow intersection, adjacent signal intersection, half cycle, split phasing.

INTRODUCTION

Diverging Diamond Interchange (DDI) is an innovative alternative to the conventional diamond interchange. The primary benefit of DDI is that it eliminates the need of protected left-turn phase, by shifting cross street traffic to the left side of the road between the signalized crossover intersections. The removal of protected left-turn phase increased effective green time for the remaining traffic movements, which translates into increased interchange throughput. DDI is a particularly attractive option for existing diamond interchanges that are structurally sound but suffer congestion due to the heavy left-turn on ramp demand. The cost of retrofitting a diamond interchange into a DDI is typically 40% or less than adding additional lanes or loop ramps to achieve the same level of capacity boost. The DDI design can often satisfy the capacity need without increasing the interchange's right-of-way. However, higher throughput at the DDI means increased traffic demands at nearby intersections. If the increased demand cannot be served by the adjacent intersections, then the DDI's capacity will be limited and the queues may spillback to the DDI and limit its capacity utilization. Signalized adjacent intersections typically have four or six or even eight phases; making it more challenging to coordinate the signal timing with DDI's 2-phase signal operation.

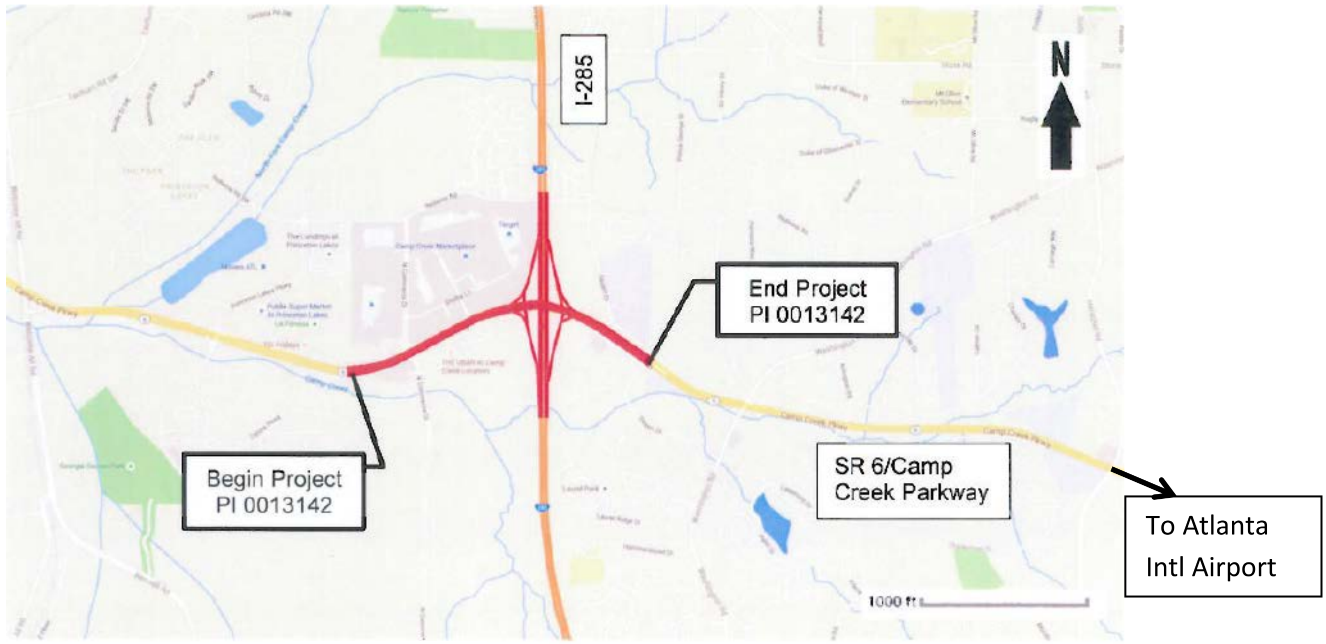
Schroeder et al. (2014) and Lloyd (2016) pointed out that the subject of adjacent intersections has been one of the major concerns noted by practitioners building and operating DDIs. Similarly, Missouri Department of Transportation (2010) and Doctor (2015) suggested that DDI may not be a suitable alternative if the interchange is located closely to adjacent signalized intersections that are experiencing heavy traffic themselves. If there are no other alternatives, and DDI has to be considered under the above situation, Schroeder et al. (2014) recommended that geometric modifications should be made to adjacent intersections to improve the operation and safety. The recommended geometric treatments include: 1) relocating the intersections to the next closest signalized intersection if possible, which was done at the DDI of I-270 and Dorsett Rd. in Maryland Height, MO; 2) using grade separation to reduce the signal phases at the adjacent intersections, which was done the at the DDI of US 60 and National Ave. in Springfield, MO; and 3) using alternative intersections to reduce the signal phases at the adjacent intersections, which was done at DDIs of I-85 @ Davidson Hwy and I-85 @ Poplar Tent Rd in Concord, NC (both used signalized superstreet at adjacent signal intersections).

This paper will focus on option 3 to investigate the feasibility and effectiveness of using alternative intersections at DDI adjacent intersections. This is the topic being investigated under NCHRP 03-113, Guidance for Traffic Signals at Diverging Diamond Interchanges and Adjacent Intersections. Zhang & Kronprasert (2015). Zhang & Kronprasert (2015) explored three alternative intersection designs to reduce the signal phases and cycle length at adjacent in intersections to DDI, including Relaxed Bowtie intersection, Superstreet, and Quadrant Road intersections. In the studied done by Zhang and Kronprasert, all three types of alternative intersection designs have the potential of turning the 6-phase operation at adjacent intersections into 2-phase operation, making them more compatible with the DDI's 2-phase operation. The simulation results showed that implementing alternative designs at DDI adjacent intersections could improve the Level of Service (LOS) at the DDI nearby intersection from D or E to A or B. Hughes et al. (2010) introduced four types of alternative intersections, including Displaced Left-Turn, Median U-Turn, Restricted Crossing U-Turn, and Quadrant Roadway. These alternative designs can all reduce the signal phases, signal cycle length, delays, and increase capacity.

STUDY SITE

The planned DDI is located at I-285 at Camp Creek Parkway (SR6) in Atlanta, GA. Camp Creek Parkway is a 4-lane divided principle arterial road that connects directly to the Hartfield-Jackson Atlanta International Airport (6.3 miles east of this interchange). At the interchange location, the freeway has 4 lanes in each direction and carries 147,000 ADT; Camp Creek Parkway has 2 through lanes and one left-turn lane in each direction, and carries 75,500 ADT. The northwest quadrant of the interchange is a shopping center with big-box stores like Target and Lowe's, hotels, retardants, and movie theaters; the southwest quadrant is currently less developed, with one gasoline station, two hotels, three restaurants, and two large warehouses that store many tracker-trailers. Figure 1 shows the project location and boundary; figure 2 shows the satellite view of the interchange and nearby intersections and projected traffic demands (PM Peak) at each intersections. The current afternoon peak hour traffic at the four signalized intersections were 5,400 VPH (SR 6 @ N Commerce DR), 5,500 (west ramp) VPH, 4,000 (east ramp) VPH, and 2,900 VPH (SR 6 @ Desert Dr), respectively. At present, the ramp terminals are congested, and the adjacent signal intersection to the west, SR 6 and N Commerce Dr, which serves the shopping center and two warehouses, is very congested.

GDOT currently uses 170 seconds signal cycle length for this corridor, and lead and lag protected left-turn phases at adjacent signal intersections. The authors investigated the current single timing plan and determined that at N Commerce Dr., it would be better to use split phasing in the N-S direction to more efficiently handle the heavy left-turn demands and prevent the problem of left-turn traffic blocking through traffic and vice versa; at the Desert Dr. intersection, since traffic demand is much less, half cycle length may be used to reduce delay. Simulation results show that the about two changes would results in moderate improvements in LOS. In the analyses presented below, the 170-sec cycle length and the half-cycle at Desert Dr. intersection were used throughout the analyses.



Project area outlined in red Source: GDOT

Figure 1 DDI Project Scope

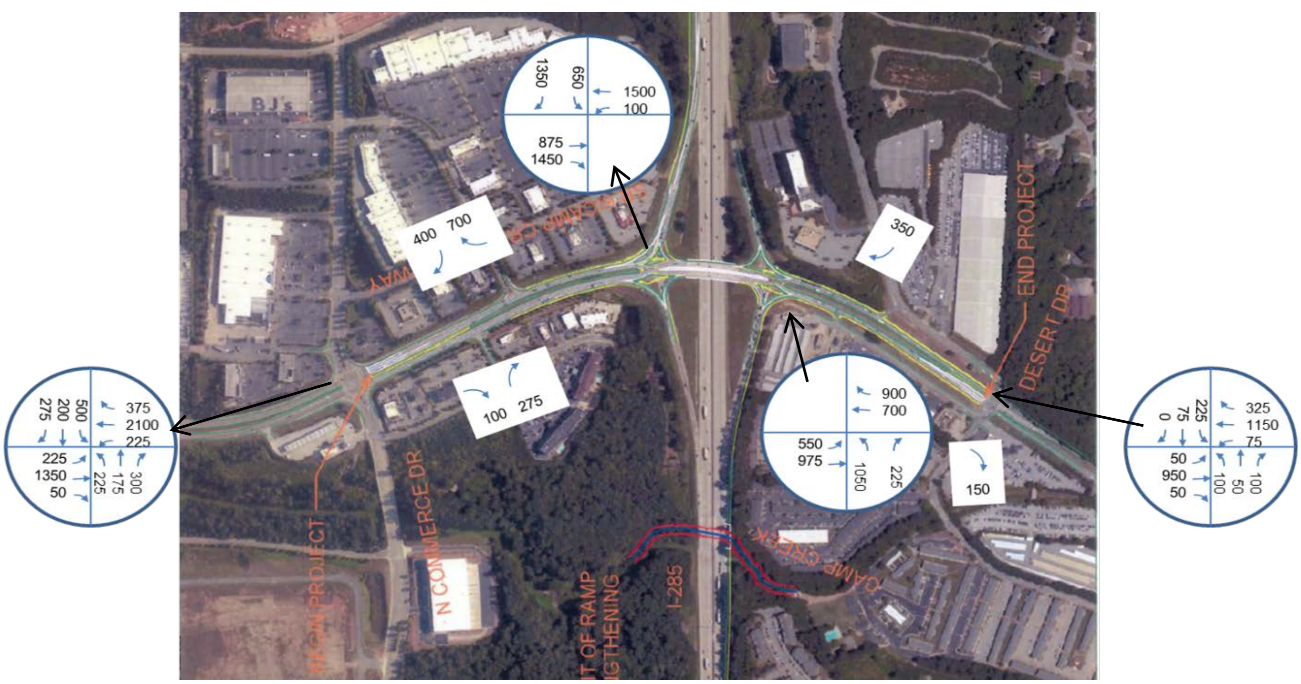


Figure 2Traffic Volume at 2020 PM

CHALLENGES

The most challenging part of the project is the signalized intersection of SR 6 and N Commerce Dr., which currently has double through, double left-turn, and single right-turn lanes in each direction (Figure 3). The SB and NB approaches both have very limited storage length. The SB approach has double left-turn lanes, single through lane, and single right-turn lane; the NB approach has single left-turn lane, single through lane, and single right-turn lane. All four quadrants of this intersection are occupied by commercial properties. The option to expand this intersection is limited. Different options were considered to improve this intersection, including split phasing of NB and SB approaches, convert it to a quadrant road intersection (QRI) or continuous flow intersection (CFI). The SE quadrant of this intersection has an existing roadway (currently bi-direction) that can be converted into the quadrant road intersection; this change requires the roadway be turned in one direction roads. For the CFI option, due to right-of-way constrain, only the partial CFI in E-W direction was considered. Because a lot of tractor-trailers use this intersection, superstreet and median U-Turn designs, both require wide median or constructing a loon on the shoulder, were not considered in this study.

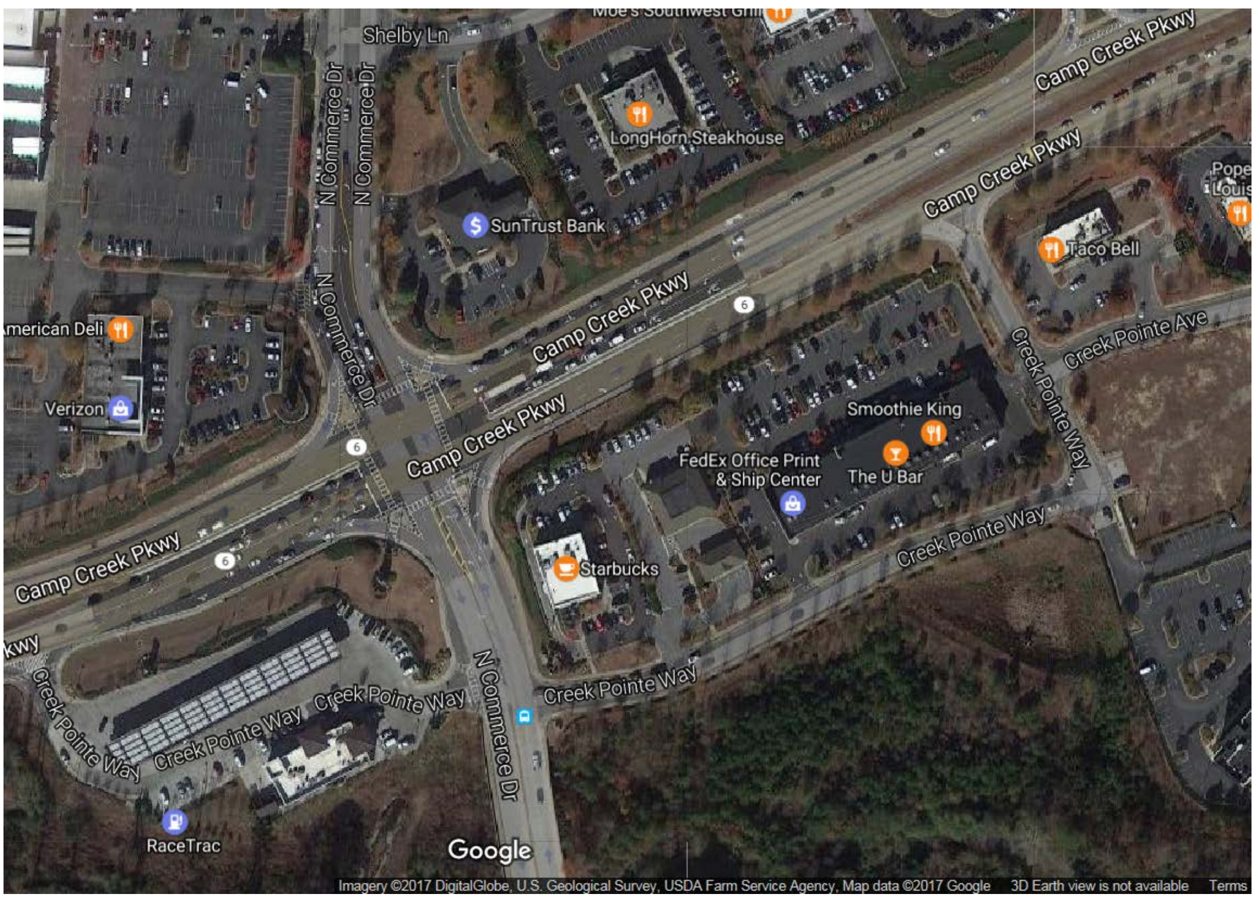


Figure 3 Close-up view of SR 6 and N Commerce Dr intersection

SIMULATION SCENARIOS

VISSIM was used to build simulation models and evaluate the performance of different design options. Four scenarios were developed to evaluate the impacts of DDI, and also to investigate the effectiveness of using alternative intersection designs at DDI adjacent intersections. Those four scenarios include:

- *Scenario 1-CDI*
  Conventional diamond interchange, this is the no build (base) condition, signal operating at N Commerce Dr. was set at split phasing, and signal operation at Desert Dr was set at half-cycle length. Signal timing was optimized for 2020 PM peak traffic volume (same for other scenarios).
- *Scenario 2-DDI*
  DDI only, in this scenario, the interchange is converted to a DDI with no changes to other intersections. Again, split phasing is used for N Commerce Dr, and half cycle length is used for Desert Dr.
- *Scenario 3-DDI+CFI*
  This scenario is built on scenario 2, with the intersection at N Commerce Dr. converted into a partial CFI (E-W) direction. To better utilize the CFI's design feature, signal option on NB and SB approaches were changes to protected left-turn phase, followed by N-S through phase.
- *Scenario 4-DDI+QRI*
  This scenario is also built on scenario 2, with the intersection at N Commerce Dr. converted to a quadrant road intersection. This change requires the loop road in SE quadrant of the N Commerce Dr. intersection be turned from a 2-way road into a one-way road. In this case, the NB and SB approaches again used split phasing prevent blocking between left-turn and through traffic.

Figure 4 and Figure 5 show the CFI and QRI designs with the highlighted routes for redirected left-turn movements. Both options remove the need of major road protected left-turn phase.

Figure 4 Partial continuous flow intersection layout at N Commerce Dr.

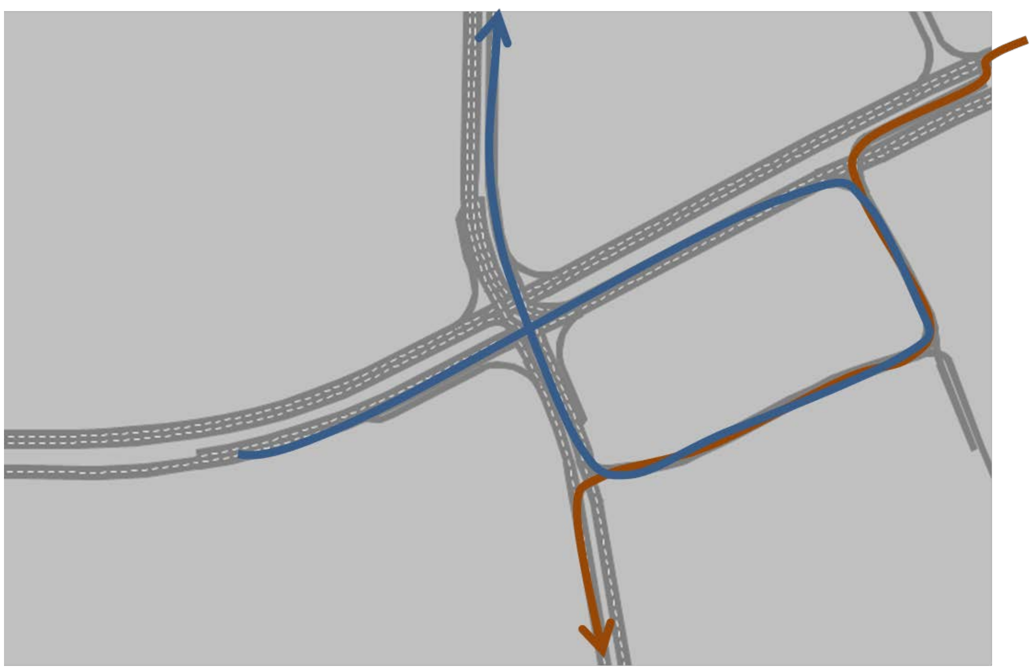


Figure 5 Quadrant road intersection layout at N Commerce Dr.

RESULTS AND DISCUSSIONS

For each study scenario, ten simulation runs were conducted, each with 900 seconds warm up period, 3,600 seconds simulation time. The measurements collected include queue length, throughput, average stop per vehicle, and delay; all MOEs were measured by approach and by movement (LT/TH/RT). To determine the intersection level of service, the intersection delays were then computed as the weighted average of approach delays (total delay divided by total traffic demand at the intersection). Tables 1 to 4 show the detailed simulation results.

Table 1 Simulation results of scenario 1 - CDI

Approach		Movement	Queue Length (ft, veh)		Throughput (veh/hr)	Average Stop per vehicle	Approach Delay (sec) & LOS			Intersection Delay (sec) & LOS	
			Average	Max							
Commence Dr.	EB	LT / TH / RT	67/150/5	210/745/244	221/1325/50	1/0.7/0.6	88.1/45.4/22.7	50.6	D	50.0	D
	WB	LT / TH / RT	63/928/496	230/1657/1659	208/1945/344	0.8/0.6/0.6	75.8/44.6/37.2	46.2	D		
	NB	LT / TH / RT	155/153/36	613/611/524	232/174/312	1/1/0.8	79.9/78.3/19.9	53.4	D		
	SB	LT / TH / RT	97/136/13	544/616/304	493/196/271	0.9/1/0.5	67.2/82.6/17.8	56.5	E		
	EB	TH / RT	61/0	298/48	892/1502	0.7/0	27.7/3.9	12.8	B	24.1	C
	WB	LT / TH	51/52	354/353	94/1606	0.8/0.4	28.8/19.6	20.1	C		
	NB										
	SB	LT/RT1/RT2	357/143/22	1460/946/409	597/414/798	1.3/0.9/0.1	88.1/38.1/11.5	42.7	D		
	EB	LT / TH	219/34	555/288	568/929	1.4/0.3	51.9/13.8	28.2	C	39.1	D
	WB	TH / RT	737/541	1245/1087	669/863	1/0.3	79.7/23	47.7	D		
	NB	LT/RT	189/3	678/153	1040/223	0.8/0.1	49/6.8	41.6	D		
	SB										
Dessert Dr.	EB	LT / TH / RT	14/45/39	112/503/503	50/922/48	0.9/0.3/0.6	46.5/13.7/23.2	15.7	B	30.6	C
	WB	LT / TH / RT	21/211/235	143/825/858	75/1124/327	1/0.8/0.7	55.6/38.4/32.5	38.1	D		
	NB	LT / TH / RT	49/49/49	300/300/300	97/50/100	1.2/1/1.2	39.8/43.3/45	42.7	D		
	SB	LT / TH	53/53	337/337	233/75	0.9/0.7	33/32	32.9	C		

Table 2 Simulation result of scenario 2 - DDI

Approach		Movement	Queue Length (ft, veh)		Throughput (veh/hr)	Average Stop per vehicle	Approach Delay (sec) & LOS			Intersection Delay (sec) & LOS	
			Average	Max							
Commence Dr.	EB	LT / TH / RT	70/163/52	225/773/566	229/1367/49	1.1/0.7/1.2	90.6/42.8/69.5	50.5	D	57.4	E
	WB	LT / TH / RT	191/1185/882	709/1674/1685	169/1882/328	1.4/0.7/0.7	141.1/52.3/44.6	56.8	E		
	NB	LT / TH / RT	211/210/76	712/711/619	229/170/308	1/1/0.7	83.2/80.3/22.6	57.0	E		
	SB	LT / TH / RT	440/440/15	1002/1003/338	469/167/242	0.9/1.6/0.7	70/145.7/50.6	72.7	E		
	EB	TH / RT	66/1	335/93	879/1483	0.7/0	29.9/4	13.6	B	22.3	C
	WB	LT / TH	129/129	557/557	93/1596	0/0.7	3.2/30.3	29.6	C		
	NB										
	SB	LT/RT1/RT2	43/312/150	247/1512/896	540/377/747	0.6/1.4/0.1	25.5/63.4/9.9	27.3	C		
	EB	LT / TH	6/6	167/167	872/546	0/0	4.5/3.7	4.2	A	15.3	B
	WB	TH / RT	128/58	844/721	684/868	1/0.1	42.5/7.8	23.7	C		
	NB	LT/RT	109/2	819/134	1021/229	0.7/0.1	19.5/5.6	17.5	B		
	SB										
Dessert Dr.	EB	LT / TH / RT	14/84/100	138/458/494	50/905/48	0.9/0.6/0.6	48.3/28.5/22.8	29.4	C	31.9	C
	WB	LT / TH / RT	19/183/208	141/786/819	74/1117/324	1/0.8/0.7	52.3/36.5/31.5	35.3	D		
	NB	LT / TH / RT	23/23/30	206/206/219	101/50/98	1.2/0.7/0.4	30.9/26/9.6	21.5	C		
	SB	LT / TH	51/51	331/331	228/72	0.8/0.7	32.4/31.8	31.9	C		

Table 3 Simulation results of scenario 3 - DDI + CFI

Approach		Movement	Queue Length (ft, veh)		Throughput (veh/hr)	Average Stop per vehicle	Approach Delay (sec) & LOS			Intersection Delay (sec) & LOS	
			Average	Max							
Commence Dr.	EB	LT / TH / RT	57/68/0	236/453/66	220/1325/50	0.9/0.5/0.4	76/29.6/9.4	35.3	D	42.5	D
	WB	LT / TH / RT	97/223/1	810/1087/128	214/1988/352	1.2/0.6/0.5	92.1/35.5/22	38.4	D		
	NB	LT / TH / RT	154/154/13	564/564/275	226/173/312	0.9/0.9/0.5	75.4/69.4/15.1	47.5	D		
	SB	LT / TH / RT	171/171/20	667/667/371	494/205/271	0.9/1/0.8	71.5/81.2/28.6	61.6	E		
	EB	TH / RT	79/0	292/0	1064/1384	0.7/0	31/3.1	15.2	B	15.3	B
	WB	LT / TH	79/79	422/422	99/1646	0/0.4	4.6/15.7	15.1	B		
	NB										
	SB	LT/RT1/RT2	48/83/0	256/424/0	564/403/782	0.7/0.8/0	23.2/31.9/1.6	15.6	B		
	EB	LT / TH	9/9	135/135	1096/503	0.1/0	4.6/2.7	4.0	A	10.5	B
	WB	TH / RT	64/4	491/280	695/877	0.8/0	33/5.2	17.5	B		
	NB	LT/RT	39/3	289/135	1037/224	0.4/0.2	11.4/4.6	10.2	B		
	SB										
Dessert Dr.	EB	LT / TH / RT	16/108/128	148/517/554	57/1075/56	0.9/0.6/0.6	49.3/29.3/25.4	30.1	C	33.6	C
	WB	LT / TH / RT	21/227/252	141/889/922	76/1122/326	1/0.8/0.7	55/37.9/33.2	37.8	D		
	NB	LT / TH / RT	30/30/36	269/269/281	96/49/101	1.2/0.8/0.6	33.4/35.9/18.1	27.6	C		
	SB	LT / TH	51/51	332/332	232/75	0.7/0.7	30.6/30.8	30.8	C		

Table 4 Simulation result of scenario 4 – DDI + QRI

Approach		Movement	Queue Length (ft, veh)		Throughput (veh/hr)	Average Stop per vehicle	Approach Delay (sec) & LOS			Intersection Delay (sec) & LOS	
			Average	Max							
Commence Dr.	EB	LT / TH / RT	69/66/0	441/421/26	208/1583/54	2.1/0.4/0.1	115.5/20.6/3.8	23.6	C	38.2	D
	WB	LT / TH / RT	70/182/161	347/1015/972	120/2021/363	1.7/0.5/0.6	102.1/25.5/24	26.6	C		
	NB	LT / TH / RT	466/474/240	964/967/960	275/394/469	1.5/1.6/1.4	85.2/98.7/44.4	73.1	E		
	SB	LT / TH / RT	105/99/9	387/380/214	517/172/290	0.9/0.9/0.3	71.4/71.2/6	52.0	D		
	EB	TH / RT	55/1	311/104	856/1441	0.7/0	25.1/2.9	11.2	B	14.7	B
	WB	LT / TH	89/89	526/526	107/1647	0/0.5	1.7/17.5	16.5	B		
	NB										
	SB	LT/RT1/RT2	46/75/0	244/418/0	580/389/798	0.7/0.8/0	25.3/33.9/3.5	17.3	B		
	EB	LT / TH	6/6	133/133	890/541	0/0	4.7/3.2	4.1	A	12.4	B
	WB	TH / RT	74/12	631/449	703/896	0.8/0.1	35.3/5.8	18.8	B		
	NB	LT/RT	79/1	521/99	1036/229	0.6/0.1	15.6/5.6	13.8	B		
	SB										
Dessert Dr.	EB	LT / TH / RT	14/88/105	131/434/471	49/923/48	0.9/0.6/0.6	48.5/29.2/23.5	29.9	C	34.4	C
	WB	LT / TH / RT	20/236/261	129/940/974	78/1143/314	1/0.8/0.8	57/38.6/35.7	39.0	D		
	NB	LT / TH / RT	29/29/35	263/263/274	95/50/98	1.3/0.8/0.6	33.5/35.9/18.7	28.0	C		
	SB	LT / TH	50/50	318/318	219/76	0.8/0.7	31.3/31.3	31.4	C		

The Effects of DDI

Comparing Tables 1 and 2, it can be seen that for the corridor network modeled, converting the diamond into DDI improves the LOS at the east ramp only; the LOS at the west ramp has barely any improvement; the LOS at N Commerce Dr. is deteriorated from D to E (because of increased traffic demand in WB direction). The LOS at Desert Dr. stays the same (slight increase in delay). The DDI increased the WB queue length at N Commerce Dr. from average of 928 ft to average of 1,185 ft, the distance between N Commerce Dr. and DDI west ramp is about 1,500 ft. The simulation results show the maximum queue of 1,674 ft, meaning periodically, the queue would spill back to the DDI ramp and affect its normal operation. This is why the LOS at west ramp sees barely any improvement between the CDI and DDI.

Compares the results in Table 2 and Table 3, one can see that by converting the N Commerce Dr into a CFI, which eliminates the protected left-turn phase on major approach, the queue on WB approach at this intersection was reduced to average of 223 ft (maximum of 1,087 ft), there is no more spill back to the DDI's west ramp. The results show that improvement at N Commerce Dr. will result in significant improvement at both interchange ramps, for the west ramp, the intersection delay will be reduced from 22.3 seconds per vehicle to 15.3 second per vehicle; for the east ramp, intersection delay will be reduced from 15.3 second per vehicle to 10.5 seconds per vehicle. Consider the total intersection demands are 5,400 VPH at N Commerce Dr., 5,500 VPH at the west ramp, and 4,000 VPH at the east ramp, the above reductions at intersection delays will results in huge savings in travel time.

Compare the results of Table 2 and Table 4, one can see that converting N Commerce Dr. into a quadrant road intersection has similar impact. This option reduces the WB queue at N Commerce Dr. to average of 182 ft (maximum of1, 015 ft), enough to prevent the queue from backing up to the DDI west ramp. This option cuts the more delay at the N Commerce Dr intersection, but cuts less delays at the west ramp and east ramp in comparison with the CFI option. The impact to the Desert Dr. intersection is similar to the CFI option – slight increase in delay but no change in LOS at Desert Dr.

The Effect of Alternative Designs at DDI Adjacent Intersection

Table 5 shows comparison of approach delays of the four scenarios. One observation is that just converting the diamond interchange into a DDI may not produce the desired improvement in LOS. By applying alternative designs to congested signal intersections adjacent to the interchange ramps, not the LOS at the adjacent intersection can be improvement, the LOS at the DDI ramps can also be improved (to the level where it should be).

Table 5 Comparison of Different Scenarios

Intersection & Approach		CDI	DDI	DDI+CFI	DDI+QR
Commerce Dr.	EB	50.6(D)	50.5(D)	35.3(D)	23.6(C)
	WB	46.2(D)	56.8(E)	38.4(D)	26.6(C)
	NB	53.4(D)	57(E)	47.5(D)	73.1(E)
	SB	56.5(E)	72.7(E)	61.6(E)	52(D)
	Intersection	**50(D)**	**57.4(E)**	**42.5(D)**	**38.2(D)**
SB Ramp	EB	12.8(B)	13.6(B)	15.2(B)	11.2(B)
	WB	20.1(C)	29.6(C)	15.1(B)	16.5(B)
	SB	42.7(D)	27.3(C)	15.6(B)	17.3(B)
	Intersection	**24.1(C)**	**22.3(C)**	**15.3(B)**	**14.7(B)**
NB Ramp	EB	28.2(C)	4.2(A)	4(A)	4.1(A)
	WB	47.7(D)	23.7(C)	17.5(B)	18.8(B)
	NB	41.6(D)	17.5(B)	10.2(B)	13.8(B)
	Intersection	**39.1(D)**	**15.3(B)**	**10.5(B)**	**12.4(B)**
Dessert Dr.	EB	15.7(B)	29.4(C)	30.1(C)	29.9(C)
	WB	38.1(D)	35.3(D)	37.8(D)	39(D)
	NB	42.7(D)	21.5(C)	27.6(C)	28(C)
	SB	32.9(C)	31.9(C)	30.8(C)	31.4(C)
	Intersection	**30.6(C)**	**31.9(C)**	**33.6(C)**	**34.4(C)**

CONCLUSION

Based on a case study of a planned DDI at I-285 at Camp Creek Parkway, simulation models were developed to evaluate the effects of DDI designs, and to explore the use of alternative intersection designs at DDI adjacent intersections. The alternative intersections tested include CFI and QRI. The study results showed that,

- For diamond interchanges that have congested signal intersections nearby, just converting the interchange into a DDI may not produce the desired level of service improvements.
- DDI design can improve the operation at the interchange itself; however, it may cause more congestion at adjacent intersections.
- Apply alternative intersection designs at DDI adjacent intersections can improve the operation at the adjacent intersection, and enable the DDI to operate at a higher level of its capacity potential.

REFERENCE

1. Schroeder, B., C. Cunningham, B. Ray, A. Daleiden, P. Jenior, J. Knudsen, Diverging Diamond Interchange Informational Guide, Report No. FHWA-SA-14-067, U.S. Department of Transportation Federal Highway Administration Office of Safety, August 2014.
2. Doctor, M., Diverging Diamond Interchange Design, 2015 Design Training Expo, June 18, 2015
3. Missouri Department of Transportation, Missouri's Experience with a Diverging Diamond Interchange-Lessons Learned, Report No, OR 10-021, May 2010
4. Zhang, W., & N. Kronprasert, Unlock DDI's Capacity by Re-Routing Left-Turns at Nearby Intersection, Access Management Theories and Practices, 2015
5. Lloyd, H., A Comprehensive Safety Analysis of Diverging Diamond Interchanges, A Thesis submitted to the Utah State University, 2016
6. Hughes, W., R. Jagannathan, D. Sengupta, and J. Hummer, Alternative Intersections/Interchange: Informational Report (AIIR), Report No. FHWA-HRT-09-060, U.S. Department of Transportation Federal Highway Administration Office of Safety, April 2010