Comparative Analysis of Conventional Diamond Interchange And Contra Flow Left Turn (CFL) Interchange

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Abstract

One of the most challenging aspects of modern day transportation engineers is to mitigate congestion so that delay faced by users is minimum. On the other hand costs associated with congestion mitigation is a big constraint. Particularly, availability of high priced right of way in urban areas motivated transportation engineers to search for alternative designs of intersections, interchanges at minimum cost but better performance in terms of lesser user delays, smaller queues and higher capacity. This paper presents a comparative study of Conventional Diamond Interchange (CDI) design with an alternative design- Contra Flow Left Turn Interchange (CFL). The two designs are analyzed for different traffic volume ranges and scenarios and the results suggest that CFL performs better than CDI in terms of lower delays and smaller queues particularly for high volume ranges.

Introduction

One of the most challenging aspects of modern day transportation engineers is to mitigate congestion so that delay faced by users is minimum. On the other hand cost associated with congestion mitigation is a big constraint. Particularly, availability of high priced right of way in urban areas motivated transportation engineers to search for alternative designs of intersections, interchanges at minimum cost but better performance in terms of lesser user delays, smaller queues and higher capacity. Several unconventional interchange designs have been developed to solve these problems. Some popular unconventional grade- separated signalized interchange designs include Echelon, Single Point Urban Interchange, Diverging Diamond Interchange, and Tight Diamond Interchange.

The Contra Flow Left Turn (CFL) interchange was first implemented in 1960s in Florida. The design replaced a Tight Diamond interchange that was failing due to the number of signal phases. The main function of CFL interchange design is to allow two opposing left turn movements from the cross street to be made during the same signal phase. Figure 1 shows the sketch of CFL. All movements in a CFL interchange are same as those of a conventional diamond interchange except for the left turn from the cross street. Cross street left turns move all into left turn storage lanes before the first ramp intersections compared to the CDI where left turns enter the interchange area with the through movements.

Past studies were interested to find the efficiency of CFL interchange compared to Tight Diamond interchange which typically has four signal phases. Since CDI is the most common form of interchanges in U.S.A in this paper we make a comparative study of interchange performance between CFL and CDI for different traffic volume range and scenarios to interpret under conditions when CFL performs better that conventional diamond interchange.

In the first part of this paper, detailed design of the interchange model is described. In the next section we describe our analysis methodology including the simulation tool used, signal designs, traffic volume levels and scenarios, performance measures. The third section includes our findings and the last part contains conclusion and recommendations for future research.

Design of Investigation

Conventional Diamond Interchange:
In this paper CDI is used as base model and compared with the performance of CFL interchange. Diamond interchange is the simplest and common form of interchange placed at the intersection of a major and minor facility. It consists of one way diagonal ramps placed in each quadrant. Diamond interchange is preferred at intersections where traffic is not expected to increase greatly over time. Figure 1 shows the layout of a conventional diamond interchange. There are two lanes on off-ramps for both north and south direction. In addition to that it has two through lanes, one dedicated left turn lane and right turn in each direction and the distance between ramps is approximately 500 ft. The model consists of two intersections with a coordinated 3 phase signal control.

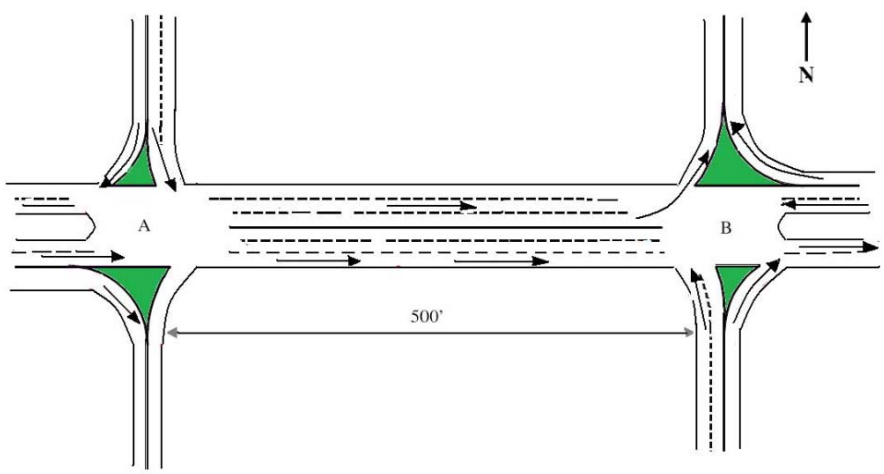


FIGURE 1 Conventional Diamond Interchange Layout.

Contra Flow Left Turn Interchange:
Figure 2 shows the layout of the CFL. It has the same configuration and movements as diamond interchange except for left turns from the cross street. Cross street left turns move over into the left turn storage lanes separated from the cross street through lanes raised median approximately 300 ft. prior to the first ramp intersection. From this left turn storage lanes vehicles move past the first signal and enter into the contra flow lanes within the interchange. These special lanes run in the opposite direction from the adjacent through lanes. Movements are indicated by following the arrow markings in the figure.

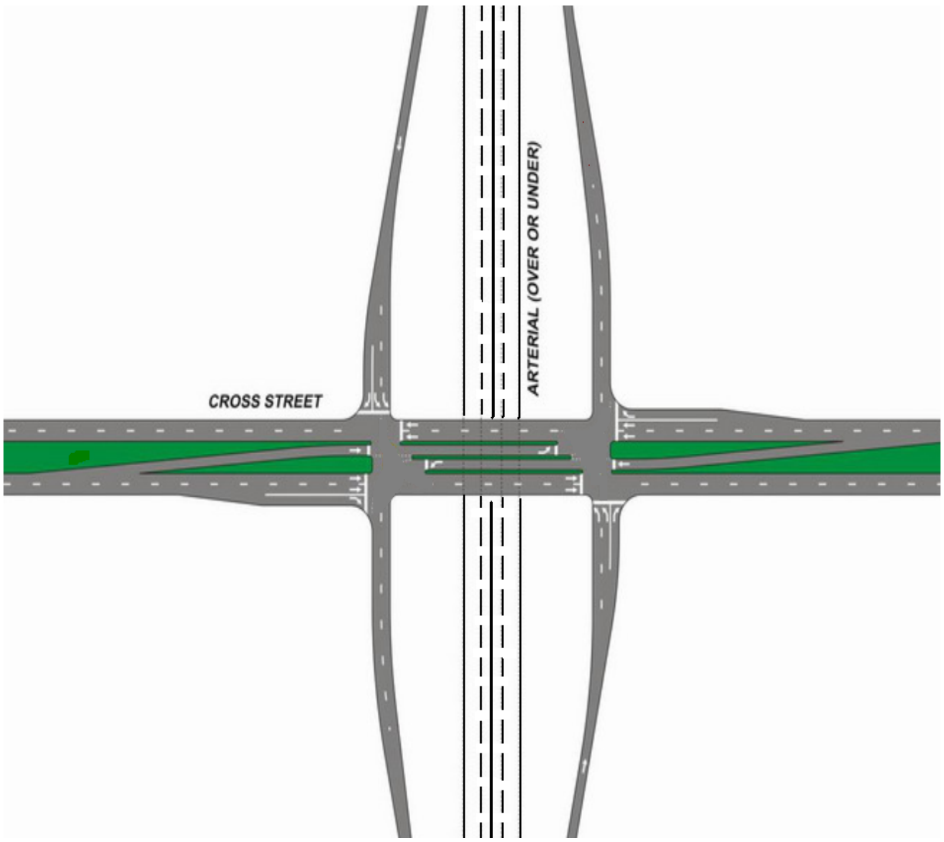


FIGURE 2 Contra Flow Left Turn Interchange Layout.

Analysis Methodology

The two models of conventional diamond interchange and Contra Flow Left Turn Interchange (CFL) is analyzed using micro simulation software VISSIM 4.3 and signal optimization software, SYNCHRO is used to set criteria for signal timings.

Analysis of the models:
Figure 1 shows the sketch of the Diamond Interchange used as a background in VISSIM and links and connectors are drawn on the top of the background. Only two vehicle types are defined in the model, namely cars and HGV, and corresponding percentages of 98% and 2% respectively are assigned to them. The desired speed for all movements ranges between 30 mph to 55 mph for both vehicle types.

Selection of an interchange is based on variety of factors such as highway classification, traffic volume and distribution, design speed, availability of right of way, degree of access control (2). However, operation in an interchange can drastically change in short periods of time depending upon traffic volume and pattern. So a number of simulations are performed to test the impact of different magnitudes of traffic volume and distribution on the operational performance of the interchange. Garber *et. al.* suggested 10 different traffic volume scenarios to be analyzed in order to capture the impact of volume distributions on interchange operations. In this paper we will concentrate on six out of those 10 scenarios which are as follow:

1. Equal cross street through and left turn volumes with balanced off-ramp movements.
2. Equal cross street through and left turn volumes with unbalanced off-ramp movements.
3. Unbalanced cross street left turn and through volumes where the heavier through volume opposing the heavier left turn volume with equal off-ramp movements.
4. Unbalanced cross street left turn and through volumes where the heavier through volume opposing the heavier left turn volume with unequal off-ramp movements.
5. Unbalanced cross street left turn volumes and unbalanced through volumes where the heavier through volumes opposes the lighter left turn volumes with equal off-ramp movements.
6. Unbalanced cross street left turn volumes and unbalanced through volumes where the heavier through volumes opposes the lighter left turn volumes with unequal off-ramp movements.

For each of these six volume scenarios four different ranges of traffic volume entering the interchange are considered – High1 (6000 vph), High2 (5600 vph), High3 (5100 vph) and Medium (3200 vph). Traffic volume in each direction is shown Table 1.

TABLE 1: Traffic Volume Distribution for Each Scenario

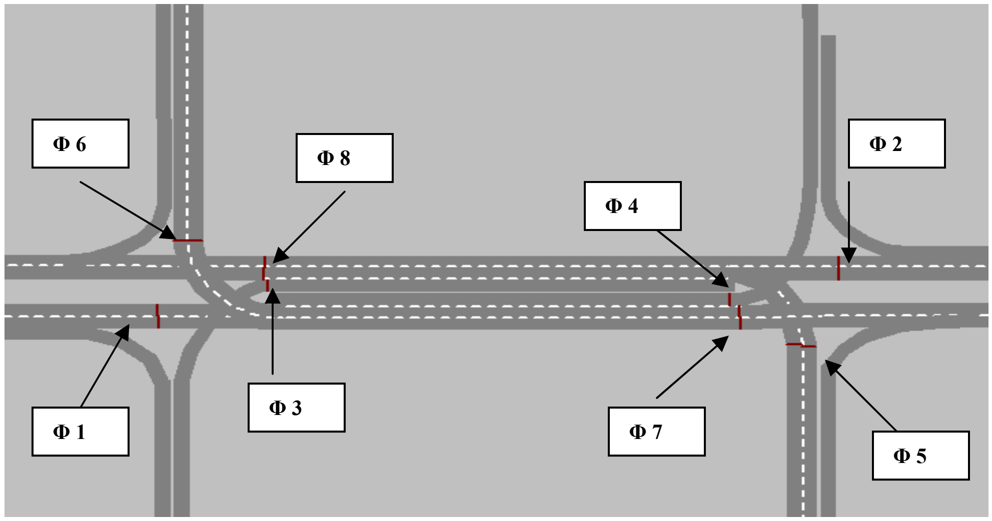
VOLUME	SCENARIO	NB		SB		EB			WB		
(veh/hr)		L	R	L	R	L	T	R	L	T	R
3200	1	400	200	400	200	200	500	300	200	500	300
3200	2	267	200	533	200	200	500	300	200	500	300
3200	3	400	200	400	200	286	333	250	114	667	350
3200	4	267	200	533	200	286	333	250	114	667	350
3200	5	400	200	400	200	286	667	350	114	333	250
3200	6	267	200	533	200	286	667	350	114	333	250
5100	1	650	350	650	350	350	750	450	350	750	450
5100	2	433	350	867	350	350	750	450	350	750	450
5100	3	650	350	650	350	500	500	373	200	1000	527
5100	4	433	350	867	350	500	500	373	200	1000	527
5100	5	650	350	650	350	500	1000	527	200	500	373
5100	6	433	350	867	350	500	1000	527	200	500	373
5600	1	700	400	700	400	400	800	500	400	800	500
5600	2	467	400	933	400	400	800	500	400	800	500
5600	3	700	400	700	400	572	533	415	228	1067	585
5600	4	467	400	933	400	572	533	415	228	1067	585
5600	5	700	400	700	400	572	1067	585	228	533	415
5600	6	467	400	933	400	572	1067	585	228	533	415
6000	1	737	450	737	450	425	837	550	425	837	550
6000	2	491	450	983	450	425	837	550	425	837	550
6000	3	737	450	737	450	607	558	456	242	1116	644
6000	4	491	450	983	450	607	558	456	242	1116	644
6000	5	737	450	737	450	607	1116	644	242	558	456
6000	6	491	450	983	450	607	1116	644	242	558	456

where High 1= 6000 vph
High 2 = 5600 vph
High 3 = 5100 vph
Medium =3200 vph

The next step of analysis provided signal timings for each volume range. Signal optimization software SYNCHRO was used to evaluate signal timings for the interchange model. For each scenario, signal timings for the highest entering traffic volume were used in the model. It was assumed that signal timings obtained from SYNCHRO is valid for oversaturated condition. The essence of our study is to capture the performance the two interchanges when there is a volume increased from the desired volume range. The signal timings obtained form SYNCHRO which are limited for under saturated condition were used for higher entering volumes (5). Signal phasing diagram for conventional diamond interchange is shown in Figure 3. It was assumed that single controller is used to control the interchange phase sequence. North bound left turners (phase 8) and south bound left turners (phase 2) go together and store in the link between the ramp terminals until phase (2) and phase (8) gets green respectively. No separate signal phase was used for right turn cross street movements. Free right turns were allowed and priority rule was coded in the model. The amber time interval used was 3 seconds and all-red interval was 2 seconds after each phase ends. Each model was run for 3600 seconds and parameters like average delay time per vehicle for each movement, travel time, average queue length and maximum queue length were collected as performance criteria for the interchange design. Further no pedestrian movement was simulated in VISSIM for the purpose of our study.

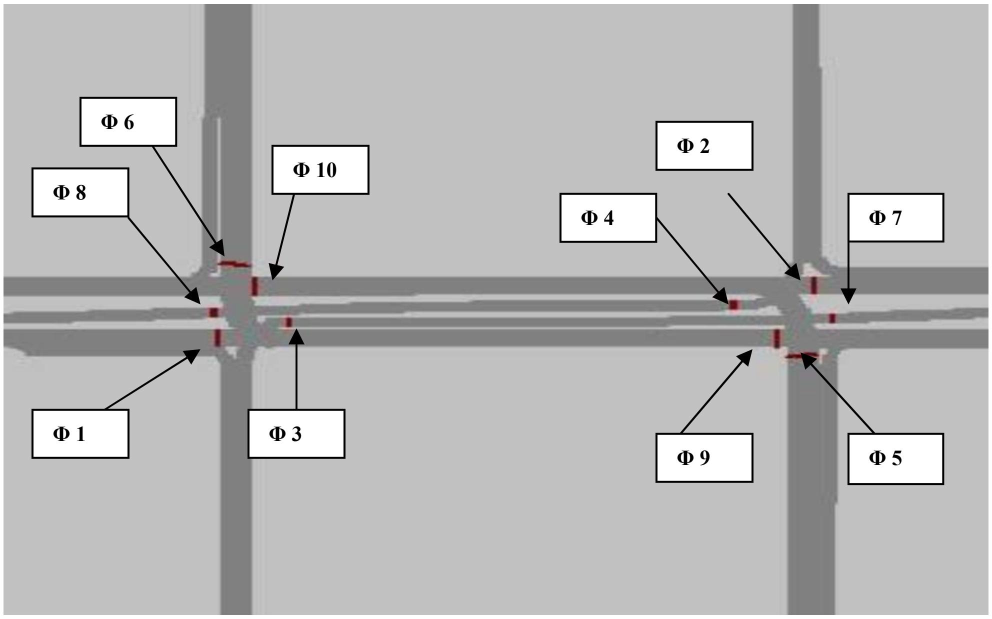
For CFL interchange same configuration was modeled as conventional diamond interchange except left turn from cross street move over into left turn storage lanes, 300 ft prior to the first ramp intersection and then enters into contra flow lanes within the interchange before making the turn onto the ramp. Similar traffic volume ranges and scenarios were considered for analysis. Signal phase diagram used for CFL is shown in Figure 4. The two opposing cross street left turn movements are made during the same signal phase. Phase 7(8) and phase 3(4) can occur simultaneously and phase 7 and 8overlap with the corresponding through movements and opposite left turn movements onto the ramp. Signal timings for each volume scenario were obtained from SYNCHRO signal optimization tool. Cycle lengths obtained for volume range High1 was used for both High 2 and High 3 range. Separate cycle length was used for medium range volume (3200 vph). The amber time used was 3 seconds and all-red period of 2 seconds at the end of each phase.

Performance criteria for CFL are analyzed based on average delay time per vehicle of each movement, average queue length and maximum queue length. All these performance criteria are compared with the CDI. Pedestrian movement was neglected in this case also.



Signal Phase (Φ)	Actual Green time in secs (Cycle length=130 secs)
1	18 to 65
2	17 to 64
3	71 to 95
4	70 to 119
5	124 to 12
6	101 to 10
7	18 to 102
8	18 to 87

FIGURE 3 Signal Settings for Conventional Diamond Model.



Signal Phase (Φ)	Actual Green time in secs (Cycle length=100 secs)
1	7 to 27
2	7 to 36
3	73 to 2
4	72 to 2
5	40 to 68
6	38 to 68
7	72 to 35
8	70 to 29
9	72 to 33
10	70 to 34

FIGURE 4 Signal Settings for CFL Model

Results

Results of traffic simulation are shown in Table 2, 3, 4 and 5. Table 2 shows comparison of average delay for each movement for scenario 1 and scenario 2. It is found that at medium volume level the difference between the two interchange models is not so significant but as the volume level increases the difference become more conspicuous. Noticeably, average delay for left turn movements from the cross streets is considerably lower for CFL compared to conventional diamond interchange. This fact is further corroborated by Figure 4 and 5 which graphically shows average delay per movement for High 1 and medium volume range. Similarly, Table 3 and 4 shows the delay comparison for other scenarios. Theses comparison suggest that CFL even performs better in scenarios where heavier left turn traffic opposes heavier through traffic in terms of average delay experienced. Table 4 and 5 shows the mean delay for the whole interchange for all high volume ranges and scenarios. The average interchange delay for CFL ranges from 26.2 seconds to 65.43 seconds which is quite acceptable compared to conventional diamond interchange where average delay ranges from 47.15 seconds to as long as 98 seconds. Figure 7 shows the average delay plot for High 1 volume of CFL and diamond interchange.

In addition to average delay, average queue length and maximum queue length for all approaches are computed for both CFL and diamond and results are shown in Table 6(a) and (b). The average queue length on east and west bound approach on cross street is considerable less in CFL compared to the diamond.

TABLE 2: Delay Comparisons between CFL and Conventional Diamond Interchange for Scenario 1 and 2

	SCENARIO 1		SCENARIO 2	
	DIAMOND	CFL	DIAMOND	CFL
VOLUME : High 1	DELAY	DELAY	DELAY	DELAY
EBLT	88.5	47.8	112	57.5
EBTH	62.2	40.8	102	38
NBLT	60.2	53.2	64.7	57.5
SBLT	66.2	52.3	96.4	50.7
WBTH	125.2	36.2	102.6	39.6
WBLT	103.3	43.6	112.6	46.7
VOLUME: High 2				
EBLT	69.1	45.6	95	56
EBTH	43.5	35.2	88	38
NBLT	55.3	55.6	59.9	57.3
SBLT	63.8	53	67.8	48.1
WBTH	102.3	36.8	68.1	37.6
WBLT	92.1	43.7	94.1	39.6
VOLUME: High 3				
EBLT	62.5	36.1	68.2	47
EBTH	37.6	34.6	38.6	36.6
NBLT	50.1	53.1	60.7	56.9
SBLT	56.5	52.7	49.3	46
WBTH	41.3	35.8	38	38
WBLT	66.7	36.9	62.7	39.2
VOLUME: Medium				
EBLT	35.3	19.8	47.1	20.3
EBTH	17.8	21.1	28.2	23.2
NBLT	31.8	30.8	35.4	27.7
SBLT	33.4	31.8	31.2	28.2
WBTH	17.8	21.8	25.2	23.6
WBLT	33.3	20.1	46.1	22.8

TABLE 3: Delay Comparisons between CFL and Conventional Diamond Interchange for Scenario 3 and 4

	SCENARIO 3		SCENARIO 4	
	DIAMOND	CFL	DIAMOND	CFL
VOLUME :High 1	DELAY	DELAY	DELAY	DELAY
EBLT	99.5	49.7	107.7	45.6
EBTH	50	43.1	58.1	41.5
NBLT	88.1	58.2	70.1	71.9
SBLT	77.4	55.3	74.2	50.4
WBTH	98.1	59.7	78.2	66.6
WBLT	108.9	43	106.9	39
VOLUME: High 2				
EBLT	86.8	48.9	90.3	43.6
EBTH	40.7	41	44.2	40
NBLT	79.1	58.8	68.3	69.9
SBLT	76.5	54.4	72.1	49.9
WBTH	82	59.4	55.2	64
WBLT	92.4	42.9	86	31.8
VOLUME: High 3				
EBLT	81.5	37.5	83.9	39.1
EBTH	40.5	39.5	39.6	39.4
NBLT	72.4	56	70.8	77
SBLT	75	53	72	36.7
WBTH	76.3	47.6	42.1	63.3
WBLT	88.4	35.9	70.4	27.3
VOLUME: Medium				
EBLT	40.2	25.3	42.3	21.7
EBTH	17.1	15.4	18.5	22.7
NBLT	37.7	28.5	21.1	25.7
SBLT	37.1	25.1	39.6	28.6
WBTH	20.1	17.9	22.1	23.8
WBLT	43.3	22.2	40.8	23

Delay values are in seconds

TABLE 4: Delay Comparisons between CFL and Conventional Diamond Interchange for Scenario 5 and 6

	SCENARIO 5		SCENARIO 6	
	DIAMOND	CFL	DIAMOND	CFL
VOLUME :High 1	DELAY	DELAY	DELAY	DELAY
EBLT	109.2	72.4	111.5	59.4
EBTH	99.2	52	109	83
NBLT	61.1	65.2	52.4	73.8
SBLT	60.1	43.2	85.3	64.6
WBTH	42.5	37.3	58	47.6
WBLT	77.6	40.2	76.5	35.4
VOLUME: High 2				
EBLT	87.2	63.2	107	60.8
EBTH	74.6	46.5	104.1	78
NBLT	58.2	61	52.5	72.7
SBLT	57.9	14.3	65.7	55.2
WBTH	39	36.5	37.4	48
WBLT	75.2	34.3	74.8	34
VOLUME: High 3				
EBLT	49.2	57.5	65.1	31.6
EBTH	32.5	40.6	47.4	64.1
NBLT	57.3	58.2	50.6	71
SBLT	55.7	13.4	59.6	16.2
WBTH	39.1	34.2	38	48.8
WBLT	72.9	41	73.4	33.9
VOLUME: Medium				
EBLT	42.4	23.2	58.7	22.4
EBTH	26.8	26.6	26.6	25.3
NBLT	44.1	29.4	44.1	26
SBLT	32.6	30.9	33.9	29.9
WBTH	27.2	22.3	27.2	22.6
WBLT	64.5	19.5	64.5	18.9

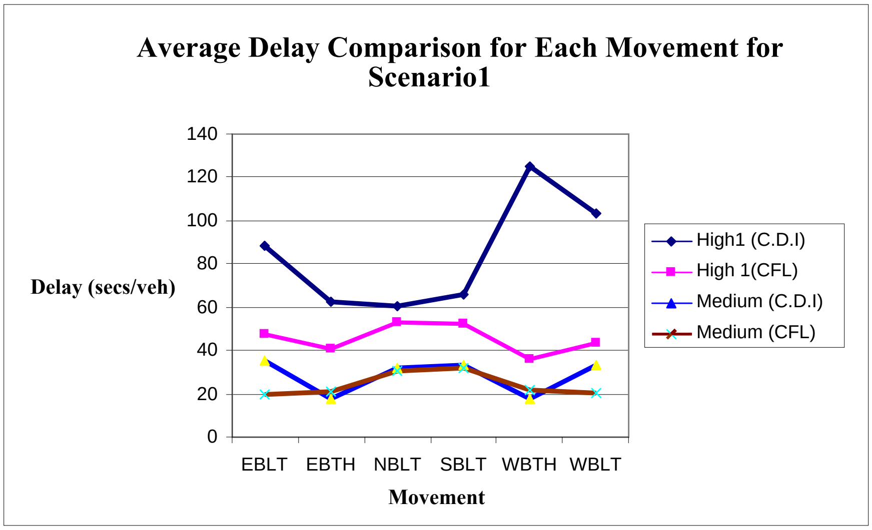


FIGURE 5 Average Delay Comparisons for Each Movement for Scenario 1

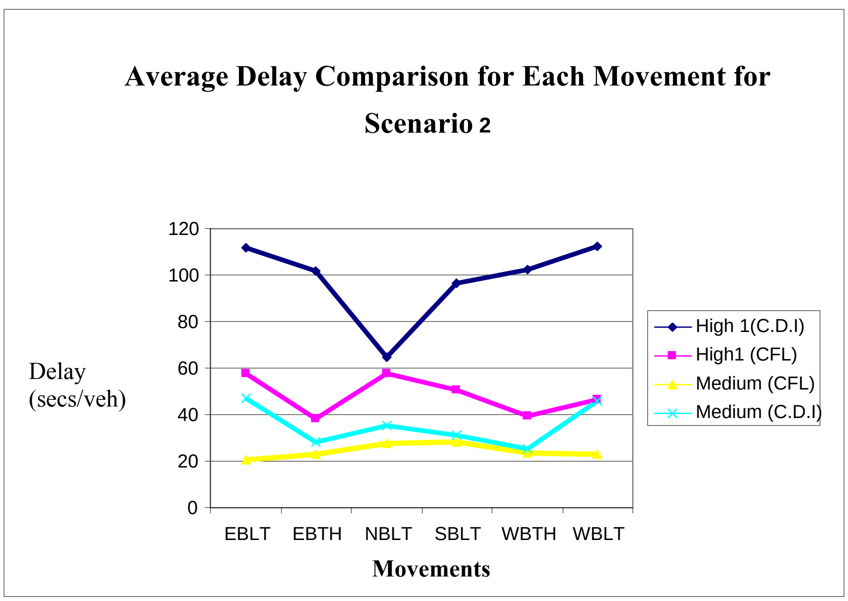


FIGURE 6 Average Delay Comparisons for Each Movement for Scenario 2

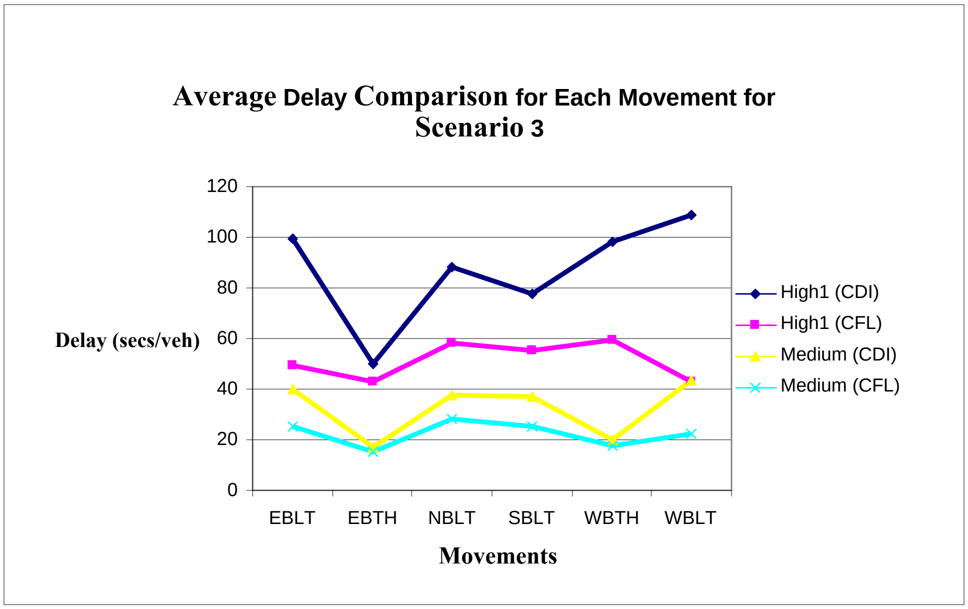


FIGURE 7 Average Delay Comparisons for Each Movement for Scenario 3.

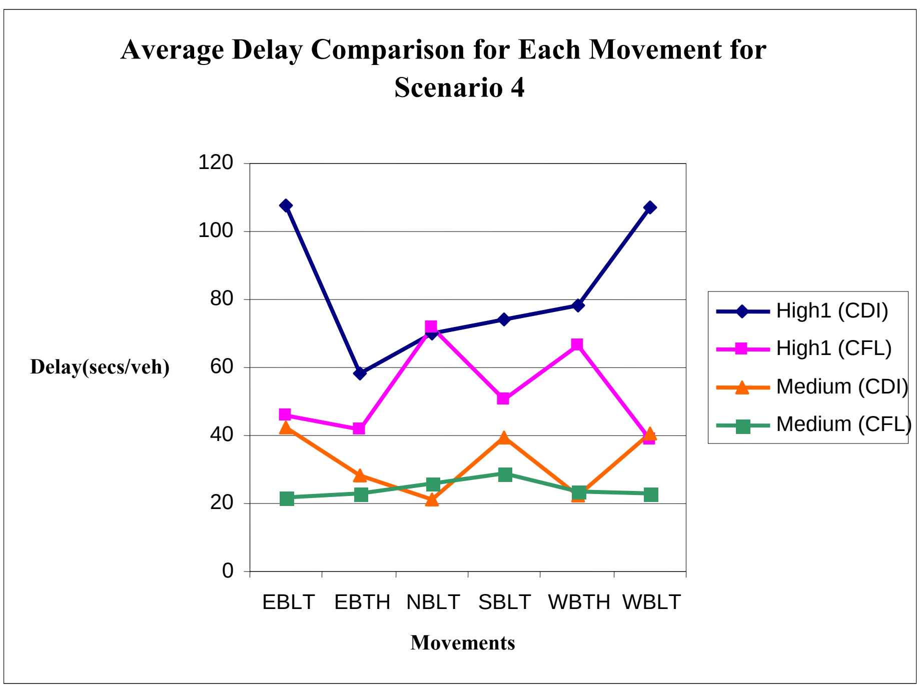


FIGURE 8 Average Delay Comparisons for Each Movement for Scenario 4.

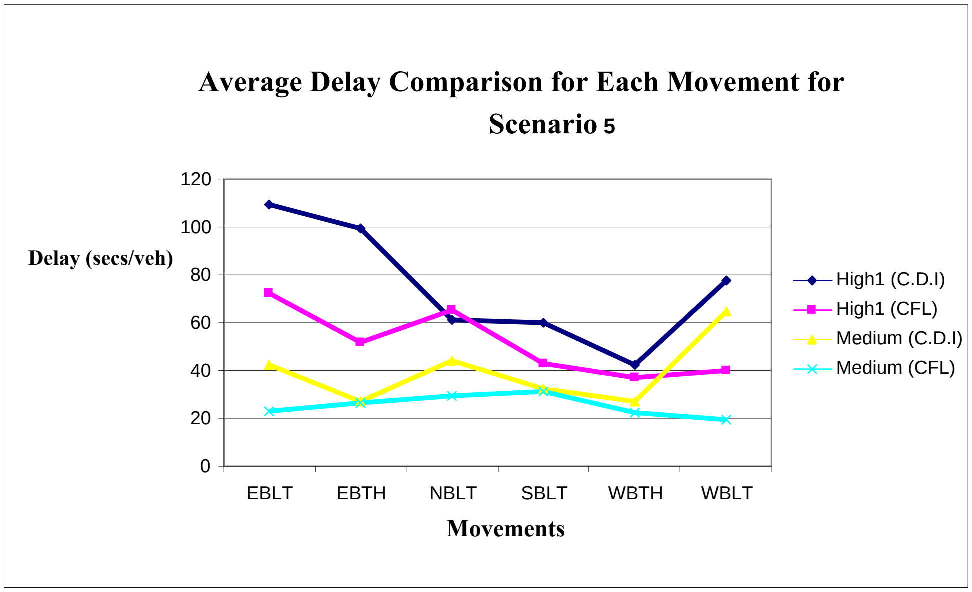


FIGURE 9 Average Delay Comparisons for Each Movement for Scenario 5.

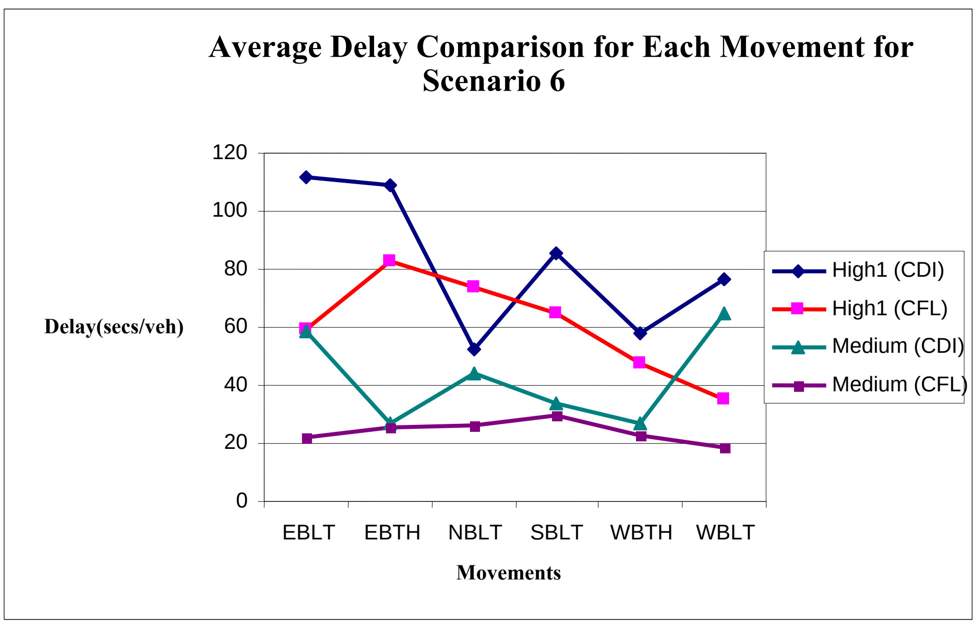


FIGURE 10 Average Delay Comparisons for Each Movement for Scenario 6.

TABLE 5(a): Mean Delay Computed for Conventional Diamond Model

D.I	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
High 1	83.14	98	86.22	79.5	77.1	89.8
High 2	69.85	76	75.99	66.2	65.77	77.9
High 3	49.6	59.5	71	60.86	47.15	53.55

TABLE 5(b): Mean Delay Computed for CFL Model

CFL	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
High 1	45.35	46.8	53.7	54.59	52.8	65.2
High 2	43.28	46.2	51.3	52.55	43.32	63.43
High 3	41.97	45.69	46.85	51.01	40.18	26.2

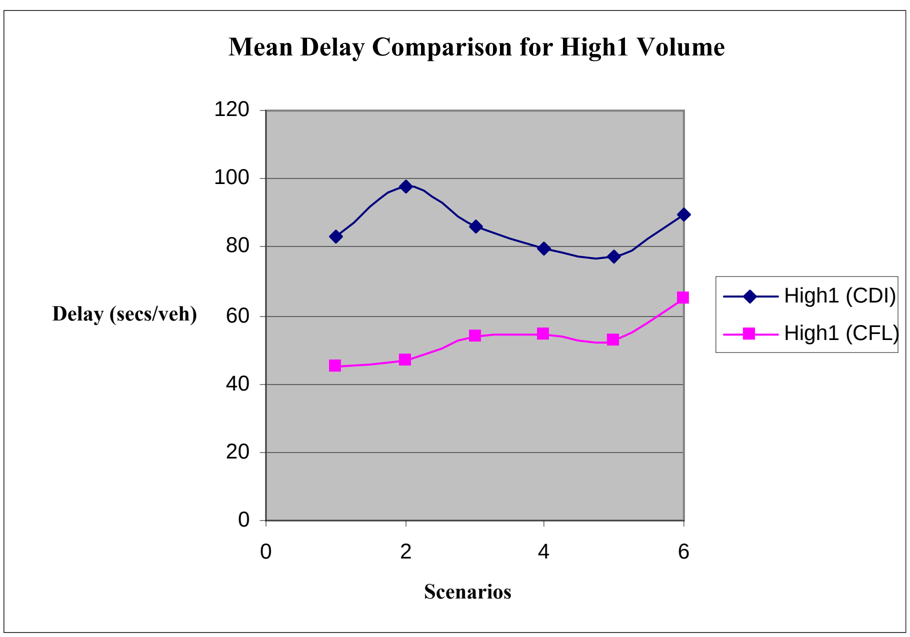


FIGURE 11 Mean Delay Comparisons for High1 Volume Range.

TABLE 6(a): Queue Length Study for Conventional Diamond Interchange for High 1 Volume

	Scenario 1		Scenario 2	
Movements	**AVG in ft**	**MAX in ft**	**AVG in ft**	**MAX in ft**
EBT(W.T)	315	1011	1236	1674
EBT(E.T)	77	317	80	336
WBT(E.T)	1172	1673	814	1654
WBT(W.T)	73	334	65	287
SBLT	109	344	253	576
NBLT	90	285	70	264
	Scenario 3		**Scenario 4**	
EBT(W.T)	271	952	361	1015
EBT(E.T)	215	527	287	528
WBT(E.T)	1176	1674	546	1450
WBT(W.T)	70	500	61	282
SBLT	79	346	106	403
NBLT	451	597	79	289
	Scenario 5		**Scenario 6**	
EBT(W.T)	1170	1674	1252	1674
EBT(E.T)	82	526	79	527
WBT(E.T)	91	395	101	349
WBT(W.T)	81	330	60	252
SBLT	78	310	200	515
NBLT	92	301	47	194

EBT= East Bound Through WBT= West Bound Through
NBLT= North Bound Left Turn SBLT= South Bound Left Turn
E.T= East Terminal W.T= West Terminal

TABLE 6(b): Queue Length Study for CFL Interchange for High 1 Volume

CFL	**Scenario 1**		**Scenario 2**	
Movements	**AVG in ft**	**MAX in ft**	**AVG in ft**	**MAX in ft**
EBT(W.T)	94	549	74	303
WBT(E.T)	69	397	62	327
WBLT(W.T)	33	184	36	352
EBLT(E.T)	34	197	40	148
NBLT	62	289	45	198
SBLT	65	314	83	551
WBLT(E.T)	64	405	70	424
EBLT(W.T)	67	540	104	548
EBT(E.T)	56	333	66	422
WBT(W.T)	56	321	51	329
	Scenario 3		**Scenario 4**	
EBT(W.T)	37	209	58	317
WBT(E.T)	154	950	125	795
WBLT(W.T)	19	118	31	217
EBLT(E.T)	102	308	80	281
NBLT	66	269	46	175
SBLT	49	224	62	295
WBLT(E.T)	47	251	11	175
EBLT(W.T)	3	356	57	359
EBT(E.T)	53	324	77	440
WBT(W.T)	43	263	145	464
	Scenario 5		**Scenario 6**	
EBT(W.T)	143	1239	208	1022
WBT(E.T)	56	237	54	241
WBLT(W.T)	7	88	63	266
EBLT(E.T)	111	359	137	307
NBLT	67	319	40	204
SBLT	56	399	89	365
WBLT(E.T)	41	212	54	239
EBLT(W.T)	146	1237	89	915
EBT(E.T)	72	494	107	369
WBT(W.T)	71	311	25	194

EBT= East Bound Through WBT= West Bound Through
NBLT= North Bound Left Turn SBLT= South Bound Left Turn
E.T= East Terminal W.T= West Terminal
EBLT= East Bound Left Turn WBLT= West Bound Left Turn

Conclusion

In this paper two interchange designs are compared and following conclusions can be made from the analysis and results:

- For all high volume ranges CFL performs much better than conventional diamond in terms of average delay and queue lengths. However, for some scenarios delay experienced by off-ramp traffic tends to be lower in diamond interchange compared to CFL when off-ramp volumes are unbalanced.
- Based upon delay and queue studies CFL is superior to diamond interchange when there is a heavy left turn volume from cross street.
- When limited left turn storage space is available between two ramp terminals CFL works better as it provides additional storage bay for left turn vehicles before first ramp intersection.

Recommendations for Future Research

A detailed analysis of capacity of CFL interchange and comparison with conventional diamond is recommended. Throughputs obtained from simulation model for increasing vehicle inputs can be used to estimate the capacity of the interchange (1). As the design suggest CFL can be a good alternative when ramp terminals are closely spaced. A comparative analysis between CFL and Tight diamond interchange (lesser ramp separation distance) can be done. Finally a cost-benefit analysis of CFL vs. CDI and Tight Diamond Interchange is recommended. This analysis could show how benefits and costs vary with different traffic volume ranges and scenarios.

References

1. Edara, P.K., J.G.Bared, R.Jagannathan. *Diverging Diamond Interchange and Double Crossover Intersection- Vehicle and Pedestrian Performance,* 3rd International Symposium on Highway Geometric Design, 2005.

2. Garber, N.J., M.D.Fontaine. *Guidelines for Preliminary Selection of the Optimum Interchange type for a Specific Location,* Virginia Transportation Research Council, January 1999.

3. Bonneson, J.A., S.Lee. *Technique for Comparing Operation of Alternative Interchange Types,* TRR Record No. 1802, 2002.

4. http://attap.umd.edu.

5. Kovvali, V.G., C.J. Messer, N.A. Chaudharuy, C. Chu. *Program for Optimization Diamond Interchanges in Oversaturated Conditions,* TRR Record No. 1811, 2002.