

Performance Evaluation of the Diverging Diamond Interchange In Comparison With the Conventional Diamond Interchange

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Abstract

The decision making process in transportation is often about making a choice between alternative solutions to a problem. To select the best alternative, the decision should be based on results from a careful study of the implications of the alternatives. This paper presents the results of a study comparing two alternative interchange designs- Diverging Diamond and Conventional Diamond Interchange. The two alternatives are studied for a range of volume scenarios using traffic micro simulation and the better performance in each scenario for Diverging Diamond Interchange in terms of delay, travel time, maximum queue length etc are reported. The comparison also consists of cost-effectiveness analysis of the two alternatives. The results from the analysis help in providing guidelines to the decision makers for selecting the best alternative in terms of performance and cost.

Introduction

The increase in surface transportation and number of vehicle miles traveled has led to new challenges for the transportation planners and engineers of ascertaining safe and uninterrupted flow of people and goods. These challenges can be met by employing some innovative and cost-effective methodologies for solving transportation problems. One of these methodologies is the Diverging Diamond Interchange (DDI).

The main goal of the DDI design is to better accommodate left-turn movements and hence eliminate a phase in the signal cycle. There is no change in the freeway portion but the off-ramp and on-ramp movements 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.

The DDI design was first suggested by Chlewicki (2) and a case study was performed using Synchro. Edara et al. (1) had earlier performed an analysis of the DDI using VISSIM for different volume scenarios and lane configurations. The results from both of these studies suggested that the DDI design outperforms the conventional interchange design for a balanced interchange traffic volume scenario. Federal Highway Administration (FHWA) has recently performed a driver's evaluation of the DDI and reported that the design has safety benefits combined with the predicted operational benefits and reduced right-of-way requirement.

In this paper we further analyze the DDI design for unbalanced interchange traffic volume scenarios. Also, this research includes a cost-effectiveness analysis of the DDI as compared with a conventional interchange design. The aim of this research is to determine the additional benefits of using a DDI design in place of a conventional interchange design in terms of user and construction costs. The results are reported and some recommendations are made on the circumstances best suitable for selecting DDI as an alternative.

The first section of the paper describes the designs of the DDI and the conventional diamond interchange under analysis. The second section describes the methodology used, model development, traffic scenarios analyzed and the type of data collected. The third section presents the results and findings of the research and the last section gives conclusions and recommendations and the need for further research.

Design of Investigation

Conventional Diamond Interchange (CDI)

The interchange connects the freeway to the crossroad with the help of two on-ramps and two off-ramps. Figure 1 shows that the CDI under analysis consisted of two through lanes and a separate left-turn lane in each direction between the ramp terminals. The approaches to the signalized intersections consisted of two through lanes and a separate right-turn lane on the arterials. The off-ramps from the freeway consisted of two left-turn lanes and a right turn lane. Both the off-ramps were single lanes. The distance between the ramps was 500 ft. Radii of crossover movements ranged from 150 ft to 200 ft and that of the left-turn movement was 100 ft.

Diverging Diamond Interchange (DDI)

Figure 2 shows that the lane configuration of DDI was similar to the CDI, but there was a change in the number of lanes between the terminals in both directions. The DDI consisted of two lanes in each direction, one through and a left-turn from a shared through and left-turn lane between the two terminals. Clearly this reduced the right-of-way requirement for the DDI as compared to a CDI between the terminals. The off-ramps consisted of two left-turn lanes and one right-turn lane. One left-turn lane and one right-turn lane led to the on-ramp. Distance between the two terminals was fixed at 500 ft. The arterial consisted of one through lane, one through + left-turn lane, and one dedicated right-turn lane. Radii of the curves were same as the radii for CDI. The design and lane configuration can be better understood with the help of the Figure.

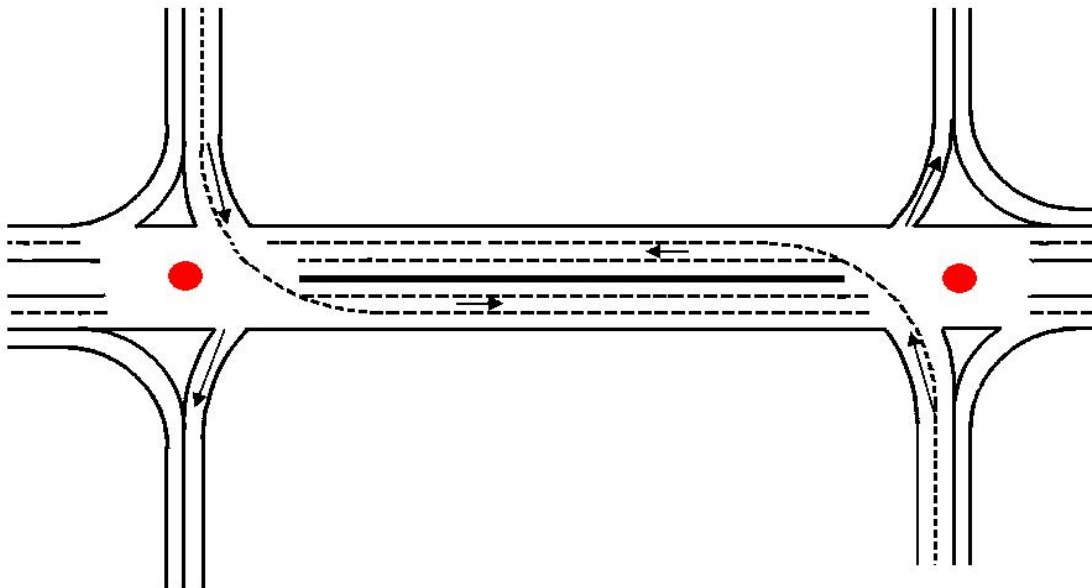


FIGURE 1 Conventional Diamond Interchange.

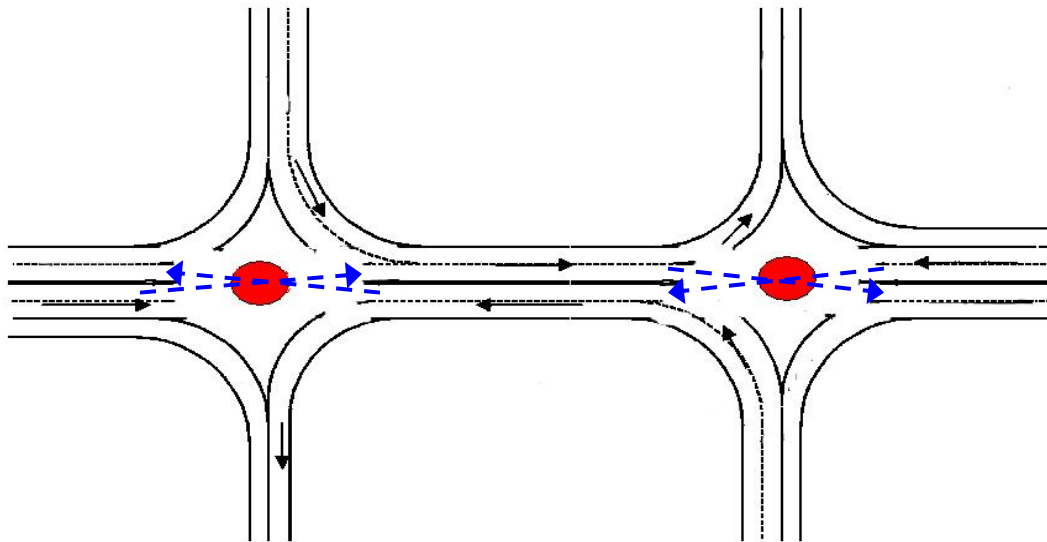
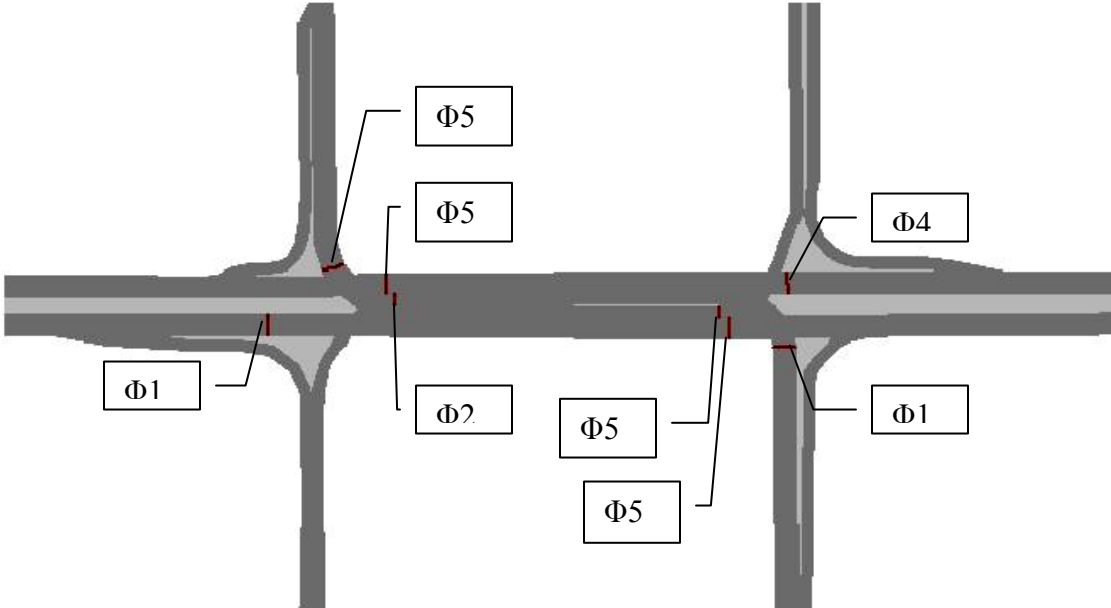


FIGURE 2 Diverging Diamond Interchange.

Model Development and Volume Scenarios

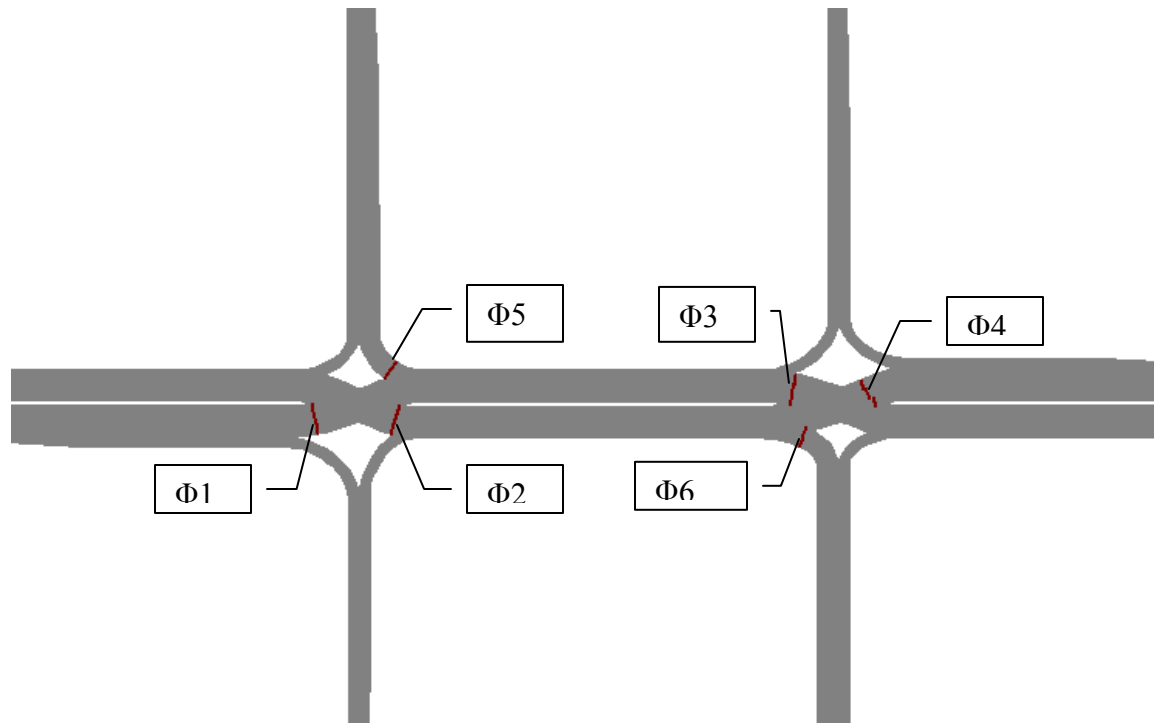
The analysis methodology followed for the performance comparison of the two interchanges is microscopic simulation. The tool used for this purpose was VISSIM 4.3. This tool was chosen due to its ability to perform a detailed analysis at the microscopic level.

The base model for the interchanges was coded in VISSIM using Figure 1 and Figure 2 as the background image. The traffic signal timings were obtained using SYNCHRO for signal optimization. As shown in Figure 3, for the CDI, a three phase signal was used and optimized signal timings were obtained. Figure 4 describes that for the DDI, a two phase signal was used at both the intersections and signal timings were obtained. It can be seen that DDI used one less signal phase than a CDI for each intersection. The total number of interchange phases for a CDI was therefore eight whereas the DDI reduced the total number of phases to six. Also, the left-turn movement leading to the ramp in a DDI transforms into a free movement thereby increasing the left turning capacity and decreasing delay. The signal timing used was optimized for the highest flow within each scenario.



Signal Phase	Green Times (sec) Cycle Length = 110 sec
1	65 to 105
2	5 to 55
3	31 to 70
4	1 to 30
5	72 to 110
6	5 to 51
7	31 to 64
8	1 to 30

FIGURE 3 Signal phases in CDI.



Signal Phase	Green Times (sec) Cycle Length = 100 sec
1	1 to 35
2	40 to 95
3	90 to 45
4	50 to 85
5	40 to 95
6	90 to 45

FIGURE 4 Signal phases in DDI.

Volume Scenarios

There was a need to develop a range of volume scenarios to achieve a broad-based comparison of the two interchange designs under similar conditions. A previous study by Edara et al demonstrated the better performance of DDI as compared to a CDI under balanced volume scenarios. Garber et al suggested in an earlier study that the spectrum of volume scenarios can be extended to unbalanced flows to analyze the performance under more field-like circumstances.

The volume scenarios developed were as follows:

- **A** Equal through volumes and equal mainline left-turn volumes
- **B** Unbalanced mainline left-turn volumes and unbalanced through volumes where the heavier through volume opposes the heavier left-turn volume.
- **C** Unbalanced mainline left-turn volumes and unbalanced through volumes where the heavier through volume opposes the lighter left-turn volume.

Each of the above scenarios was further divided into five increments of traffic flow as follows:

- High 3 – Traffic flow of 6200 vph
- High 2 – Traffic flow of 5600 vph
- High 1 - Traffic flow of 4500 vph
- Medium - Traffic flow of 3200 vph
- Low - Traffic flow of 1700 vph

Results

The simulation models for the two interchanges were run for a period of 3600 seconds and data collected for delay and queue length over the time period are as follows:

	Delay(sec/veh)		Max Queue(ft)	
	CDI	DDI	CDI	DDI
High 3	118.4	66.7	1457	478
High 2	96.3	46.3	1330	410
High 1	67	35.8	1079	320
Medium	46	28	460	242
Low	31.4	21	273	192

TABLE 1 Scenario A Comparison

	Delay(sec/veh)		Max Queue(ft)	
	CDI	DDI	CDI	DDI
High 3	156.8	77.4	1659	795
High 2	133.7	64.5	1107	578
High 1	95.2	47	732	465
Medium	46.9	25.1	506	280
Low	45.7	23.4	295	158

TABLE 2 Scenario B Comparison

	Delay(sec/veh)		Max Queue(ft)	
	CDI	DDI	CDI	DDI
High 3	124	65.7	1674	717
High 2	93.3	56.9	1410	597
High 1	67	38	589	465
Medium	47	22.6	396	373
Low	48.2	12.6	231	204

TABLE 3 Scenario C Comparison

Capacity

The capacity comparison for the critical movements of the two interchanges is as follows:

Capacity for Scenario A showed an increase in off-ramp capacity by 88 % and an increase in left-turning capacity by 74 %.

Capacity	NB off-ramp	SB off-ramp	EB		WB	
	L	L	L	T	L	T
DDI	720	916	883	883	1080	1080
CDI	393	393	540	1064	344	867

NB-Northbound EB-Eastbound L-Left-turn
 SB-Southbound WB-Westbound T-Through

TABLE 4 Scenario A Comparison (Capacity)

Capacity for Scenario B showed an increase in off-ramp capacity by 83 % and an increase in left-turning capacity by 62 %

	NB off-ramp	SB off-ramp	EB		WB	
	L	L	L	T	L	T
DDI	600	600	600	600	600	600
CDI	310	310	344	490	344	490

NB-Northbound EB-Eastbound L-Left-turn
SB-Southbound WB-Westbound T-Through

TABLE 5 Scenario B Comparison (Capacity)

Capacity for Scenario C showed an increase in off-ramp capacity by 85 % and an increase in left-turning capacity by 59 %

Capacity	NB off-ramp	SB off-ramp	EB		WB	
	L	L	L	T	L	T
DDI	835	475	998	998	638	638
CDI	450	432	630	1134	234	720

NB-Northbound EB-Eastbound L-Left-turn
SB-Southbound WB-Westbound T-Through

TABLE 6 Scenario C Comparison (Capacity)

The following graph explains the variation of delay with flow for the two alternatives of DDI and CDI.

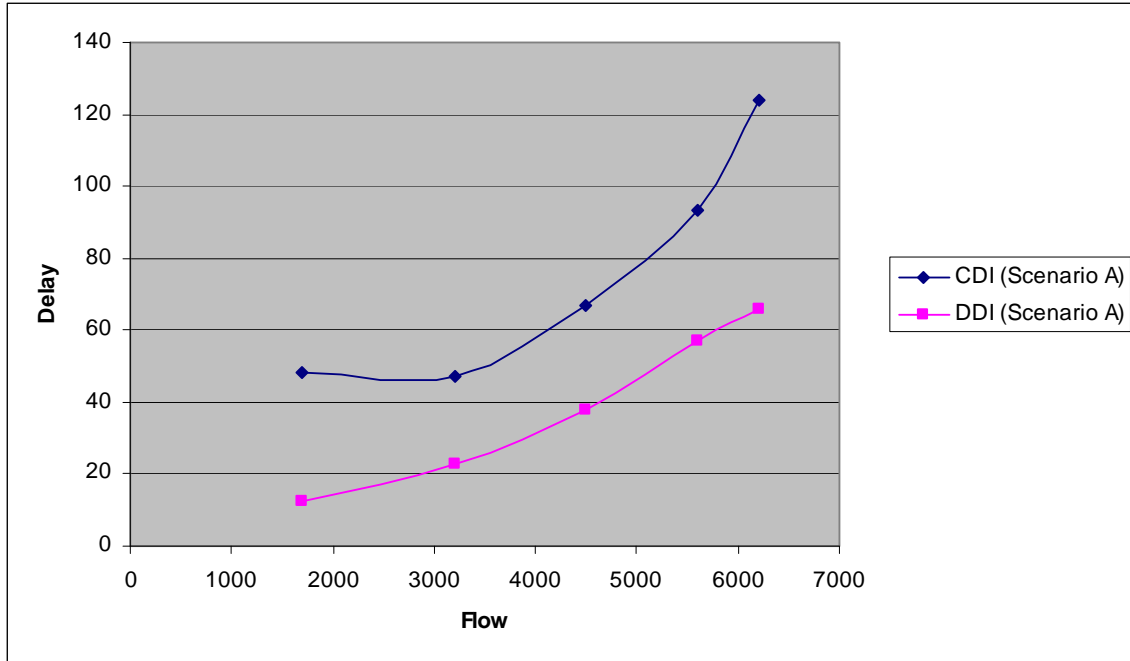


FIGURE 5 Average Delay v/s Flow Scenario (A).

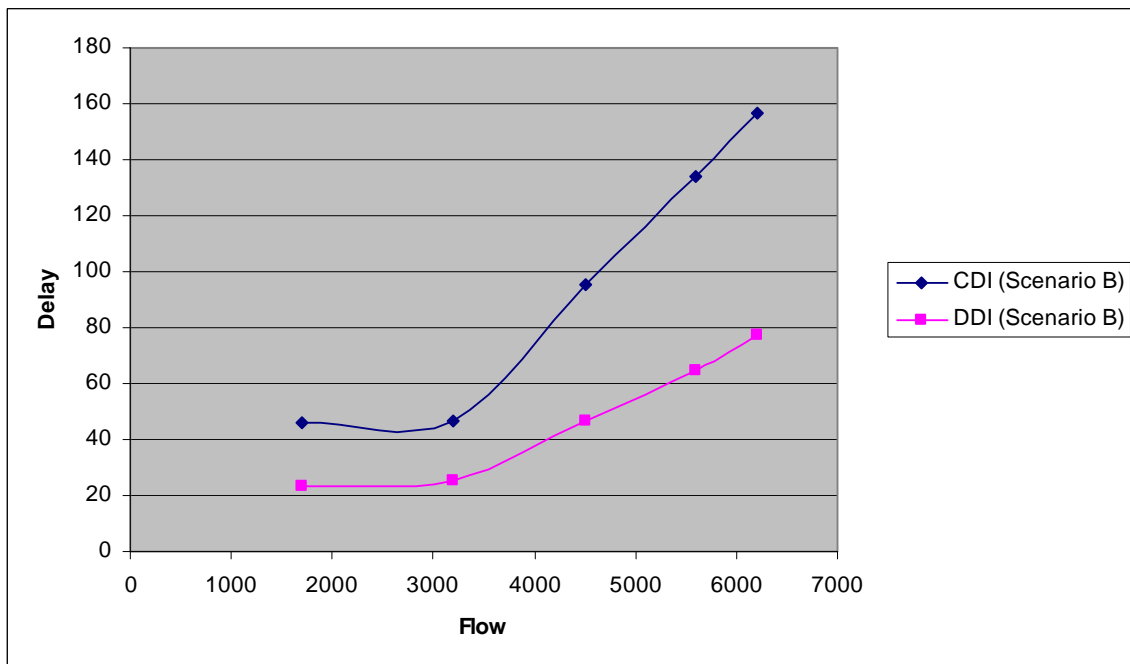
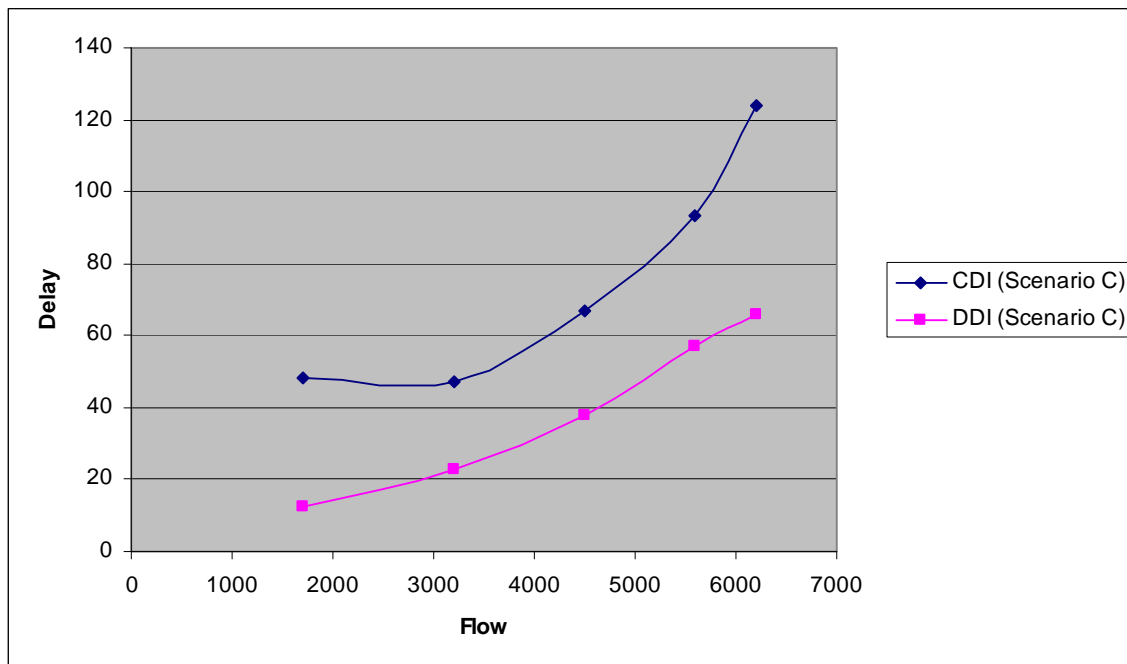


FIGURE 6 Average Delay v/s Flow Scenario (B).**FIGURE 7 Average Delay v/s Flow Scenario (C).**

Discussion of results

Results from the traffic simulation are as shown in Tables 1, 2, and 3. The Tables compare the delay and maximum queue length for the three volume scenarios. In all the cases, DDI performed better than the CDI. This difference was largest at high flow levels. At low and medium flows the performance for both the designs was identical. As the flow was increased further the delay and maximum queue length for CDI were found to be considerably greater than DDI. It is seen that the DDI is particularly effective in the worst case scenario (Scenario B) where the heavier left-turn movements are opposed by the heavier through movements.

The signal timings were created to minimize delay; however the timings also control the critical movement capacity. Tables 4, 5, and 6 show the capacity estimates for all signalized movements for the two designs. For the balanced interchange traffic scenario (Scenario A), the DDI outperformed the CDI for the left-turn movements leading to the on-ramps. In case of scenarios B and C the increase in capacity for the left-turn movements was greater for DDI than the CDI by more than 50 %.

The designs of the two interchanges differ for the section of interchange between the ramp terminals. It can be seen in the figure that the DDI has one less lane than a CDI for the same traffic volume scenario. The DDI gave a lesser delay for the vehicles even with a one less lane in each direction.

Conclusions and recommendations

After comparing the performance measures under various traffic scenarios for the two interchange designs the following conclusions can be made:

- In all the traffic scenarios, the performance of DDI was found to be better than CDI with lower delays for critical movements, lower travel time and lower maximum queue lengths.
- DDI showed increased capacity for the critical movements, particularly the left-turns, even for each traffic scenario.
- The DDI option can apparently provide superior operation to the CDI. When performance of CDI with 4 lanes is unacceptable, a 4-lane DDI may be a superior option to building a 6-lane CDI.
- Since the delays are reduced for a DDI, it would significantly reduce the time cost and the vehicle operation cost experienced by the user.
- The reduced numbers of signal phases in a DDI better accommodate the traffic than a CDI.
- Since driver expectations were not addressed in this study, the unfamiliarity with the design of DDI might lead people to accept the relatively poor performance of the CDI for low to medium traffic volumes.

Need for Future Research

Cost-effectiveness analysis of DDI with evaluation with respect to user cost benefits needs to be done. Safety aspect of this innovative design needs a further analysis since the concept is totally new to drivers. This task can be performed with the help of the Surrogate Safety Assessment Model (SSAM) being developed by FHWA. A comparison of DDI with Single point urban interchange (SPUI) should be done particularly with the point of view of accommodating higher left-turn movements.

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