

University of Nevada, Reno

**An Evaluation of Operational Efficiency between Single Point Urban Interchange with
frontage road and Tight Diamond Interchange**

A thesis submitted in partial fulfillment of the requirements for the
degree of Master of Science in Civil and Environmental Engineering

By

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THE GRADUATE SCHOOL

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ABSTRACT

Signalized urban interchanges are frequently used as junctions between freeways and local arterials to date. In recent years, many new interchange or intersection designs like Diverging Diamond Interchange (DDI) and Continuous-flow Intersection (CFI) have emerged across the world. However, most of the interchanges are still using conventional urban interchange designs. Among new designs, Single Point Urban Interchange (SPUI) and Tight Diamond Interchange (TDI) are the most popular. Comparison and evaluation of the safety and operation of interchanges are important in transportation engineering to choose the most appropriate option for a location. Recently, many research have been devoted to the standard TDI and SPUI. Most of them consistently prove that the SPUI outperforms TDI in operation efficiency, but few research have compared the SPUI with frontage road (SPUI-F) with TDI.

This research aims to fill this gap. With this motivation, there was a real case which could be used as testing the operational efficiency between the TDI and SPUI-F. The Nevada Department of Transportation (NDOT) switched the TDI, which was located at I-580/Plumb Ln, to SPUI-F in 2003. Since this interchange has experienced TDI and SPUI-F, the Measures of Effectiveness (MOEs) for each of them can be compared.

To perform this comparison, layouts of both interchanges were modeled in VISSIM. The models were calibrated using the existing volume. Several volume scenario groups were designed for testing the operational efficiency of both options. Three MOEs, including average delay, average speed and average queue length, were selected to show the operational efficiency. The results revealed that the TDI is more efficient in comparison to the SPUI-F. However, TDI might not satisfy the driver's expectation because of the stopping between the two signals, for which SPUI-F does not have such a problem.

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GLOSSARY OF ACRONYMS

CDI: Compressed Diamond Interchange

CFI: Continuous Flow Interchange

DDI: Diverging Diamond Interchange

DI: Diamond Interchange

EBL: Eastbound Left Turn

FHWA: Federal Highway Administration

LOS: Level of Service

MoDOT: Missouri Department of Transportation

MOEs: Measures of Effectiveness

MOEs: Measures of Effectiveness

MUDI: Michigan Urban Diamond Interchange

NBL: Northbound Left Turn

NDOT: Nevada Department of Transportation

PFI: Parallel Flow Interchange

RVs: Recreation Vehicles

SBR: Southbound Right Turn

SPUI: Single Point Urban Interchange

SPUI-F: SPUI with Frontage Road

TDI: Tight Diamond Interchange

TRINA: Traffic Record Information Access

TTI: Texas Transportation Institute

WBL: Westbound Left Turn

TABLE OF CONTENTS

ABSTRACT.....	i
ACKNOWLEDGEMENT	ii
GLOSSARY OF ACRONYMS.....	iii
TABLE OF CONTENTS.....	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
CHAPTER 1 INTRODUCTION	1
1.1 Definitions	1
1.2 Problem Statement	2
1.3 Research Objectives.....	3
CHAPTER 2 LITERATURE REVIEW	5
2.1 Operational Features and Applications of SPUI	5
2.2 Operational Features and Applications of TDI	6
2.3 Studies Regarding Operation and Safety	7
2.3.1 <i>The Operation Development of the SPUI and TDI</i>	7
2.3.2 <i>The Safety Consideration of Two Interchanges</i>	9
2.4 Existing Research Shortcoming.....	9
CHAPTER 3 CASE STUDY.....	11
3.1 Case Study Site Background.....	11
3.2 Current Operating Issues at the Site.....	12
3.3 Layout of SPUI-F.....	13
3.4 Layout of Diamond Interchange	14
CHAPTER 4 MODEL CALIBRATION AND VALIDATION.....	15
4.1 Speed Calibration.....	15
4.2 Maximum Queue Length Validation	16

CHAPTER 5 EVALUATION METHODOLOGY OF TDI AND SPUI-F	21
5.1 Evaluation Method.....	21
5.2 Volume Scenarios Design.....	21
5.3 Signal Operation Setting.....	24
5.4 Phase Sequences and Overlaps	27
5.4.1 <i>SPUI phase sequence</i>	27
5.4.2 <i>TDI phase sequence</i>	28
5.5 Simulation Parameters	29
CHAPTER 6 EVALUATION RESULTS AND ANALYSIS	31
6.1 Base Scenario Group.....	31
6.2 Scenario 1 (One Approach Heavy Left Turn Scenario Group).....	34
6.3 Scenario 2 (Two Approaches Heavy Left Turn Scenario Group).....	37
6.4 Scenario 3 (One Approach Heavy through Scenario Group).....	39
6.5 Scenario 4 (Two Approaches Heavy through Scenario Group).....	42
6.6 Scenario 5 (One Approach Heavy Ramp Scenario Group)	44
6.7 Scenario 6 (Two Approach Heavy Ramp Scenario Group).....	47
Chapter 7 Conclusion and Future Works	50
REFERENCE	53

LIST OF TABLES

Table 1 OD Matrix of the PM Observation Results.....	15
Table 2 Volume Scenario Groups.....	23

LIST OF FIGURES

Figure 1 The Layout of SPUI (Left) and TDI (Right), [1].....	2
Figure 2 The Layout of SPUI-F	3
Figure 3 Satellite Image of the Field Condition for SPUI-F at I-580/Plumb Lane	12
Figure 4 Layout of SPUI-F in VISSIM.....	13
Figure 5 Layout of TDI in VISSIM	14
Figure 6 Static Origins and Destinations	15
Figure 7 The Trend Variation of EBL Maximum Queue	17
Figure 8 The Trend Variation of SBR Maximum Queue	18
Figure 9 The Trend Variation of WBL Maximum Queue	19
Figure 10 The Trend Variation of NBL Maximum Queue	20
Figure 11 SPUI-F Basic Timing	24
Figure 12 TDI Basic Timing.....	25
Figure 13 Cycle Length Trend of SPUI for Base Scenario's Default Case.....	26
Figure 14 Cycle Length Trend of TDI for Base Scenario's Default Case.....	27
Figure 15 SPUI-F Phase Arrangement and Sequence	28
Figure 16 TDI Phase Arrangement and Sequence	29
Figure 17 Average Delay for Base Scenario Group	31
Figure 18 Average Speed for Base Scenario Group	32
Figure 19 Average Queue Length for Base Scenario Group	33
Figure 20 Average Delay of Scenario 1.....	35
Figure 21 Average Speed of Scenario 1.....	35
Figure 22 Average Queue Length of Scenario 1.....	36
Figure 23 Average Delay of Scenario 2.....	37
Figure 24 Average Speed of Scenario 2.....	38
Figure 25 Average Queue Length of Scenario 2.....	38
Figure 26 Average Delay of Scenario 3.....	40
Figure 27 Average Speed of Scenario 3.....	40
Figure 28 Average Queue Length of Scenario 3.....	41
Figure 29 Average Delay of Scenario 4.....	42
Figure 30 Average Speed of Scenario 4.....	43
Figure 31 Average Queue Length of Scenario 4.....	43

Figure 32 Average Delay of Scenario 5.....	45
Figure 33 Average Speed of Scenario 5.....	45
Figure 34 Average Queue Length of Scenario 5.....	46
Figure 35 Average Delay of Scenario 6.....	47
Figure 36 Average Speed of Scenario 6.....	48
Figure 37 Average Queue Length of Scenario 6.....	48
Figure 38 MOEs Results Summary	52

CHAPTER 1 INTRODUCTION

The introduction section will document the definitions of the subjects in the research, clarify the problem statement and go over the research objectives. The geometry layout of a typical SPUI and TDI are provided in this section as well as the motivation behind conducting the research analysis.

1.1 Definitions

The Tight Diamond Interchange (TDI) and the Single Point Urban Interchange (SPUI) both belong under the category of the Diamond Interchange (DI), which is the most used design in signalized interchanges. The SPUI was first invented in 1970 and aims to improve traffic capacity compared to the conventional diamond interchange. With this design, all of the turning movements of the crossroads and ramps converge to the center. Normally, the span of a SPUI bridge has a length from 160ft to 280ft. As for the TDI, it is usually used in urban and suburban areas where the right of way is a constraint. The TDI design was evolved from the Conventional Diamond Interchange with a space between two signalized intersections of 200ft to 400ft. It has two closely spaced signalized intersections at the crossing of the ramp terminals and side street. Generally, the span of a TDI is from 140ft to 180ft. Figure 1 illustrates the layout of a SPUI and TDI.

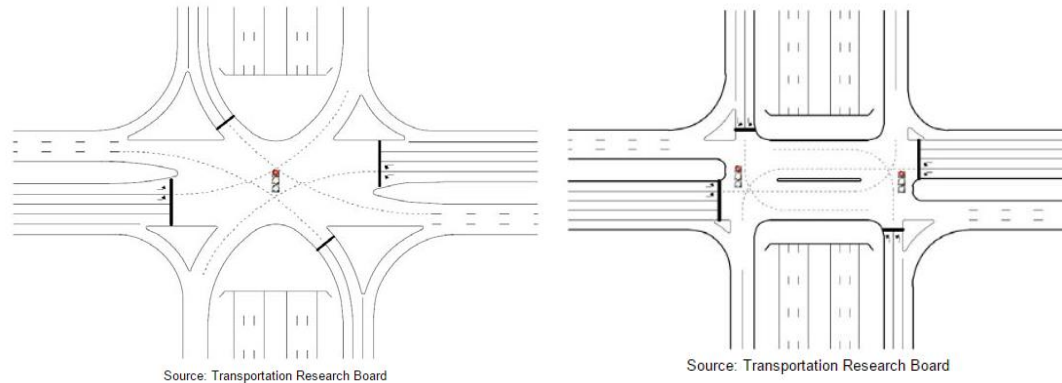


Figure 1. The Layout of SPUI (Left) and TDI (Right), [1]

1.2 Problem Statement

Interchanges are among the most important parts of road networks. They are normally used to connect the urban freeways and arterials. That means an interchange will serve thousands of commuting traffic every day. Thus, the operational efficiency of interchanges is of significant importance to be thoroughly investigated. Among those urban traffic interchanges, Diverging Diamond Interchange (DDI) was recently developed and its popularity has since spread quickly. However, when there is a new proposed interchange, the DIs are still the priority because of their familiarity by drivers and reliable performance. Among those conventional designs, the SPUI and TDI are two of the most frequently discussed. There have been continued debates on the operational efficiency and safety issues of them. Recent studies indicated that the operation of SPUI is more efficient than TDI. However, few studies evaluated the operational efficiency of SPUI with frontage road (SPUI-F). With this motivation, this research conducted a comprehensive evaluation towards the operational efficiency of SPUI-F, and TDI. The Figure 2 illustrated the layout of a SPUI-F.

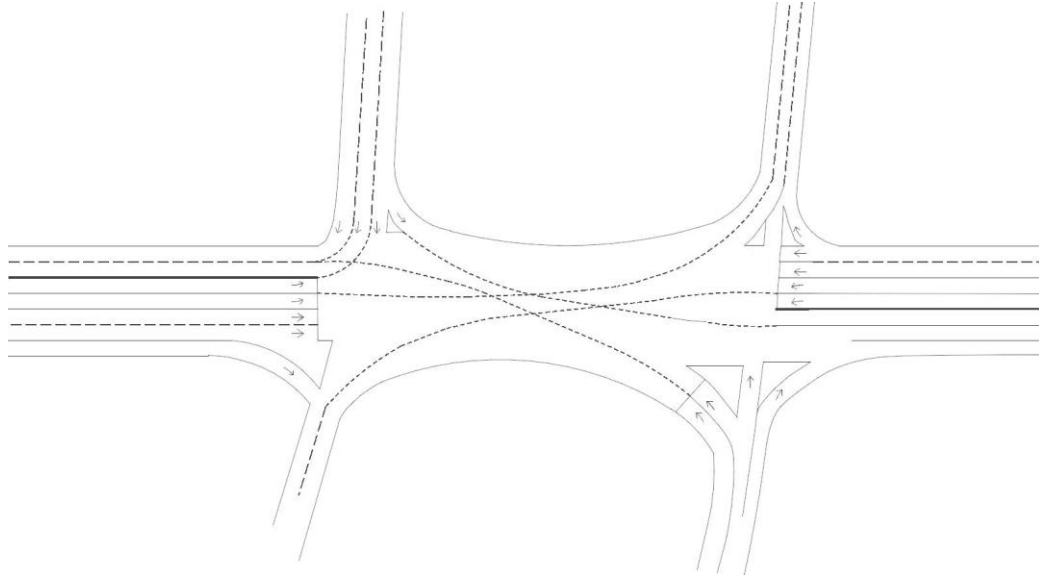


Figure 2 The Layout of SPUI-F

According to the record of the Nevada Department of Transportation (NDOT), an interchange revision project was found. The project started in 2003 focused on revising a TDI to a SPUI-F. The reason why it still kept the frontage road was that the two frontage roads connected to another cross road located to the north of the interchange. Thus, the project offered an excellent field example. With this motivation, this research followed the geometric of the SPUI-F in the project and revised the SPUI-F to TDI with the same lane configuration.

1.3 Research Objectives

This thesis tried to answer a question regarding the operational of SPUI-F compared to TDI. It aimed to investigate the signal operational efficiency and conduct an evaluation between the SPUI-F and TDI. The unfamiliarity of SPUI-F by drivers is the primary disadvantage of the SPUI-F, but it does not mean SPUI-F causes more safety issues because even new designs like the DDI [2], Continuous Flow Intersections (CFI) [3], and Parallel Flow Intersections (PFI) [4] are widely implemented and becoming more and more prevalent. However, traffic engineers also recommended TDI to replace SPUI due to SPUI's large and uncontrolled conflict area. Because of

the lack of guidelines for the selection of SPUI-F and TDI, this research proposes a VISSIM road network model to evaluate the operational efficiency of two interchanges.

This research will conduct a controlled computer simulation to evaluate the operation efficiency of SPUI-F compared to TDI. The volume was obtained by field data collection and modified by Traffic Record Information Access (TRINA). The optimal signal timing plan for two kinds of interchanges were selected to conduct research. The VISSIM was selected as the microscopic simulation software. For the case study, the identical volume scenarios were applied to two interchanges. The interchanges' geometry layouts are consistent with the field study conditions. Average delay, average speed, and average queue length were selected as MOEs to perform the comparisons. The model calibrations were conducted using the Origins and Destinations volume. Seven scenario groups were designed; they are default scenario group, one approach heavy left turn scenario group (scenario 1), two approaches heavy left turn scenario group (scenario 2), one approach heavy through scenario group (scenario 3), two approaches heavy through scenario group (scenario 4), one approach heavy ramp scenario group (scenario 5), and two approaches heavy ramp scenario group (scenario 6). For the sensitivity analysis, each of the scenarios will have five volume cases. This research will give a general conclusion about the selection between the two interchanges.

The rest of this thesis is as follows. A literature review of SPUI and TDI is offered in Chapter 2; the calibration of the VISSIM road network is demonstrated in Chapter 3; the volume scenario groups design is presented in Chapter 4; Chapter 5 shows the MOEs comparisons; and Chapter 6 summarizes the findings and future works.

CHAPTER 2 LITERATURE REVIEW

This chapter summarizes the previous works regarding both types of interchanges. The operational features and the applications, the operational development and the safety development of both interchanges will be documented accordingly. The existing research shortcomings are discussed at the end of the chapter.

2.1 Operational Features and Applications of SPUI

This section will mainly introduce the characteristic and application of the SPUI. The characteristic parts focus on the introduction of the pros and cons to the SPUI, while the application parts will introduce the invention of the SPUI, adoptive situations of SPUI, and new SPUI designs.

To make a useful comparison of both interchanges, the advantages and disadvantages of SPUI are important to note. The first advantage of SPUI is the less right-of-way requirements compared to other interchange types because of the less conflict points [5]. With this advantage, the overlaps of the dual left turn movements can be used in operation. The overlaps make the SPUI have more potential capacity compared to the DI. Another advantage is the wide radius design [6], which will offer large radius geometry in design. This design allows Recreation Vehicles (RVs) and freight trucks easier passage. Also, the wide radius design could increase the speed of the vehicles and therefore contribute to the efficiency. Finally, the less conflict point also makes the interchange safer. According to the reported data, injuries and fatalities were significantly less than the DI because of the less conflict points. Apart from those advantages, the disadvantages are also considered. The major disadvantage for the SPUI is that the implementation requires a longer span of the bridge and more land for the dedicated left turn lanes. On the other hand, because of the different entry points to the interchange, the open area of the SPUI is larger. With the unfamiliarity by the drivers, the safety issue is of utmost importance.

The application of the SPUI has been found all over the world. This brilliant design was invented by Wallace Hawkes, Director of Transportation Engineering at J.E. Greiner, Inc [7]. The first application was adopted by the Florida Department of Transportation on the SR 60 in Clearwater, Florida [7]. After that, more and more regions adopted this design. In Hong Kong, the Kwai Tsing interchange used the design of SPUI [8]. In Indonesia, the National Route 1 has the SPUI design implemented on its mainline [8]. In Singapore, the SPUI was implemented in Eunos Flyover [8]. SPUI was also widely accepted in Australia [8].

Apart from the conventional SPUI design, some of the revision designs were also implemented in the field. An inversed TDI design was used in Interstate 290 near Chicago [9]. These applications show that SPUI has great potential for further development. Although, the TDI is the more common interchange used in the world because of its familiarity to drivers.

2.2 Operational Features and Applications of TDI

This section will introduce the characteristic and applications of TDI. In consistency with the previous section, the advantages and disadvantages and applications of TDI will be discussed.

The most important advantage of TDI is that the interchange geometry is familiar to the majority of drivers. Unlike the SPUI and DDI, TDI configuration does not confuse the drivers. DDI shifts the right-hand traffic to the left-hand side at the intersections. Drivers who are not accustomed to this method do not quickly adhere to the new routes since TDI appears just like two regular intersections. Drivers do not need to think about the entrance and the exit of the two intersections in this case. The second advantage of TDI is that it is well suited in urban areas with less required land. Unlike the SPUI, the TDI does not require the dedicated left turn lanes. Thus, span of the bridge could be shorter and the land use could be less. Apart from those advantages, it still has some inerascable shortcomings. The first shortcoming is that since the interchange appears like normal intersections, the unshaded off-ramp frustrates drivers. That would result in a greater

possibility of wrong entry. In order to avoid the situation, most of the diamond interchanges address the wrong way by using the sign at the off ramp. Another shortcoming is that it reduces the level of service (LOS) as the traffic volume increases. That means TDI does not perform well during congested volume scenarios. This might be improved if better timing plans are provided.

The control for TDI has many variations. That might be a reason why TDI is still much more popular than SPUI. For TDI, either three phase control or four phase control could be selected. A variation of four-phase control named TTI-4 phase [10, 11, 12] control is now widely accepted. It is an operational method which overlaps the ramp phases and the through phases. With this type of control, the TDI could be accommodated to the driver's expectations and maximize the efficiency.

2.3 Studies Regarding Operation and Safety

This section summarizes the previous studies related to the SPUI and DI. The information gathered was separated into two perspectives: (a) the operational issues of the SPUI and DI, and (b) the safety issues of SPUI and DI.

2.3.1 *The Operation Development of the SPUI and TDI*

The basic signal timing patterns for SPUI consists of two types: three phase pattern and four phase pattern. Typically, three phase pattern is used in the majority of SPUI designs because of the higher operational efficiency and various overlaps. However, an additional phase should be added when frontage roads are existing in the interchange to negotiate the conflicting movements as Bonneson has mentioned [13]. Leisch et al. conducted a comparison of two DI forms in urban areas which indicates that for most situations, the Compressed Diamond Interchange (CDI) was better than SPUI in regards to their operational efficiency [14]. In the study, five field examples were employed into the simulation by TRANSYT 7F; results showed that the SPUI outperformed CDI at only one

location. However, more and more recent research show that the SPUI operates obviously better than DI. A research conducted by Jones and Selinger [15] illustrated that the SPUI provided better system operational performance than TDI. This research [15] conducted more specific scenarios analysis; the balanced volume, heavy ramp volume, and 60/40 directional test cases were individually tested. This research mentioned that the study results were different from the previous research. After that, additional research was performed to evaluate the operational efficiency of these two types of interchanges. Bonneson [16] studied the headway and lost time of SPUI, and found that traditional methods for estimating the average minimum discharge headway and start-up lost time may be biased. It mentioned that the through movements headway is larger than At Grade Intersections (AGIs) while for the left-turn movements, the larger radius of the SPUI resulted in minimum headways that are about 0.12 sec shorter than AGI. Then, Dorothy et al. [17] conducted a field analysis of operation and design of single point urban interchange. In this research, an outstanding design was introduced named MUDI. The conclusion from the MUDI design indicated that dedicated U-turn lanes are not necessary for SPUI. Among these research, some important conclusions were selected as the guidelines for selecting SPUI and DI [18]. Bonneson divided the variations of the TDI to three types: TDI, CDI, and DI, which was very helpful to the classification for future researchers' studies. This review mentioned, at least under certain circumstances, that the SPUI has more advantages than TDI. Besides this comparison, a guideline for selecting simulation software was generated. Hardware in the loop simulation of DI was conducted by Koonce et al. [19]. The test compared the hardware in the loop simulation to the field study and found that hardware in the loop simulation was more accurate than those simulations that depended on the software. Lee et al. [20] set up an assessment test to three simulation models: Corsim, SimTraffic, and SYNCHRO. The conclusion was that SimTraffic is the most reliable software among those three.

2.3.2 The Safety Consideration of Two Interchanges

The safety was widely discussed for these two interchanges. The safety issue is related to the geometric designs, driver behavior and even signal timing. Smith [21] investigated the safety issues through the accident experience. The research was divided into two sections that outlined the dominant factors contributing to accidents and compared the DI and SPUI with their safety. The results showed that the drivers' unfamiliarity of SPUI was not a major factor that affected the safety. In fact, the other factors did not greatly affect safety. However, it mentioned another issue, that the rear-end crash type is the predominant crash type of SPUI. This conclusion also received the support from Bonneson and Messer from TTI. Messer [22] also conducted an analysis of the conflicts of traffic. She found that in most cases, the all red interval was shorter than the actual time taken to clear the intersection. So the conflict was frequently observed between clearing the off-ramp and entering the crossroad left-turn movements. The off-ramp right turn also conflicted the cross through traffic. However, according to this study, there was no evidence showing the SPUI's traffic accident rate was more than AGI. Also, the Federal Highway Administration (FHWA) mentioned that SPUI has fewer conflict points than the CDI and TDI. So in some degree, the SPUI could provide safer conditions than the TDI in operation.

2.4 Existing Research Shortcoming

From the existing research, it was mentioned that if a frontage road were included, the operational efficiency of SPUI would be decreased. Yet, it lacks the evidence from the previous operational efficiency research. Leisch [23] mentioned that with the frontage road, the delay increase of SPUI would be approximately 30%. However, these results have not been tested again for almost 30 years. Over the years, most of the research illustrated operational efficiency evaluation procedures, and the outcomes showed that at least the SPUI would perform better than TDI in some cases. Once the different opinions were held, more and more research was conducted focusing on SPUI and

TDI. Among the majority of studies, the SPUI seems to have a higher performance over TDI. However, it does not mean the research by Leisch was wrong because under different geometries, the results may vary. The volume and the timing plans were not introduced in his research, and also it did not rely on any practical applications.

In this research, the operational efficiency for SPUI-F and TDI will be discussed. Different scenario groups were selected, and field data was used to derive the evaluation results. The VISSIM microscopic simulation analysis was used to determine how the SPUI-F and TDI would operate in the field.

CHAPTER 3 CASE STUDY

This chapter introduces the case study in this research, the background, current operational issues and how the case study was applied in the research.

3.1 Case Study Site Background

The case study site is the I-580/Plumb Lane interchange. Originally, this interchange was a TDI operated by two separate controllers. Over the years, the traffic volume totally changed and it was later changed to a SPUI-F without concrete evidence of which interchange had the better performance. Although most of the guidance indicated that the SPUI outperformed the TDI in operation, no comprehensive evaluation indicated the preference of the SPUI-F compared to TDI. Missouri Department of Transportation (MoDOT) [24] reported that the SPUI has less traffic conflict points than the TDI. However, it does not mean that the SPUI-F has the same conflict points so it could not be inferred that the potential crash probability could be lower than TDI regardless of driver's unfamiliarity to this design. Also, it might be an improvement towards the average vehicle speed of the interchange because of the wide radius design. It could not operate using dual left turn strategy because the frontage road will have the conflict with the left turn movements.

The SPUI-F is composed of the two frontage roads and two ramps. This feature is consistent with the typical design. However, the lane configuration is different from the typical SPUI. There is a heavy volume movement at the southbound right turn movement during PM peak hour. For the southbound left turn movement, since the volume is not heavy, there is only one left turn lane. The details of the lane configurations and the road curvature geometry is shown in Figure 3.

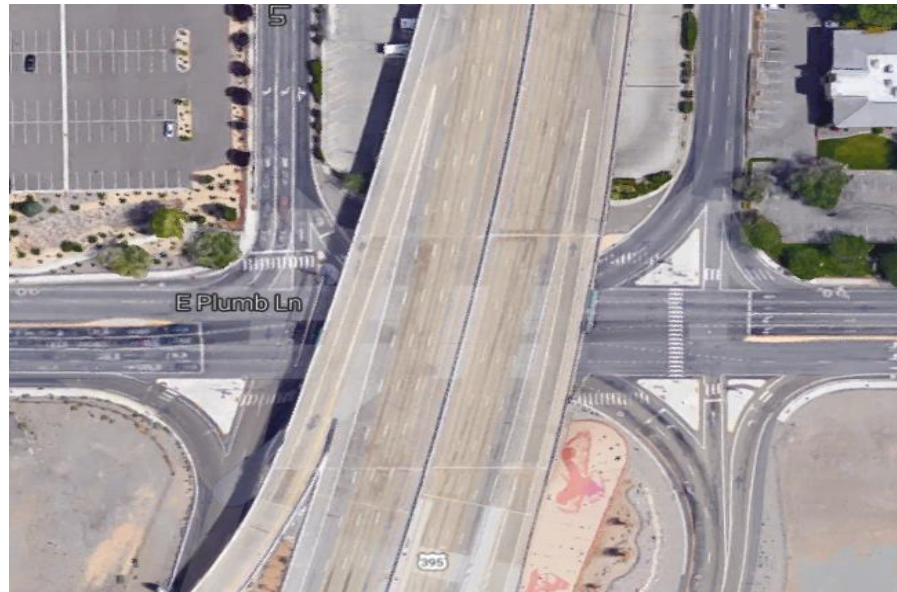


Figure 3. Satellite Image of the Field Condition for SPUI-F at I-580/Plumb Lane

3.2 Current Operating Issues at the Site

Currently, the SPUI-F is operated by various cycle lengths ranging from 110 seconds to 170 seconds. The controller of the interchange is now running with a free pattern. Since the volumes attributed by different approaches and intervals are uneven, it is unable to fix the controller timing. For the eastbound direction, the traffic from East Plumb Ln is heavy during the peak hour, so it will spill back to the entrance of the Costco if the vehicles keep queuing. For the westbound direction, vehicles are approaching from the airport. The congestion is highest at peak hours but also at any given time when flights arrive simultaneously. In other words, the adjacent intersection to the east of the SPUI-F is too close to the SPUI-F thus it is not eligible to serve a heavy volume. In summary, the traffic volume pattern may change significantly in a short time. Thus, the free pattern may be the most appropriate timing design.

Another issue that should be taken into consideration is that the SPUI-F is not available for right turn on red for the southbound frontage road because of the existing two exclusive lanes for right turn vehicles. With this design, the right turn vehicles conflict with westbound through traffic.

Since there is a frontage road for the through movement design, the SPUI-F could not use three phase operations. An additional phase was required to avoid the conflicts between ramps phases.

3.3 Layout of SPUI-F

Before introducing the operational evaluation, the layout of SPUI-F needs to be clarified first. All approaches of SPUI-F converge into one intersection which could be controlled by a single signal. For the field conditions, lane configurations and other geometric characteristics may vary. In this research, the SPUI-F has channelized right turn lanes in three approaches. For the southbound, there are two right turn lanes adjacent to the through lane as there is large right turn volume. For the southbound left turn, only one lane is offered. Unlike the typical SPUI design, the interchange does not have a center island. The rest of the characteristics are similar to the traditional SPUI. The VISSIM layout is shown in Figure 4.

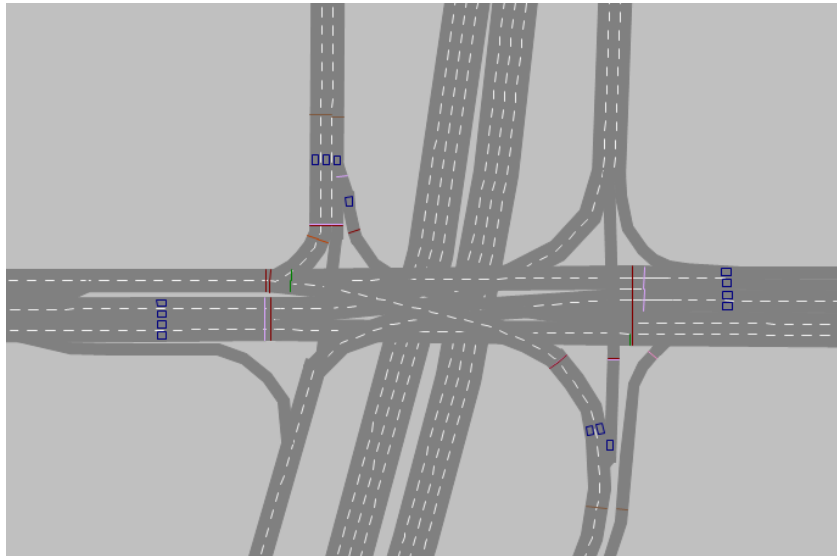


Figure 4. Layout of SPUI-F in VISSIM

3.4 Layout of Diamond Interchange

The TDI in this research has the same scale as was in place before 2003. Actually, the TDI was constructed following the same geometry of the SPUI. The width is the same for both interchanges. The layout of the TDI is illustrated in Figure 5. The exterior road network keeps the same lane configurations and locations with SPUI-F. The difference is in the interior road network, which has the different geometry and radius design regarding the SPUI. Other characteristics are consistent with the traditional TDI features.

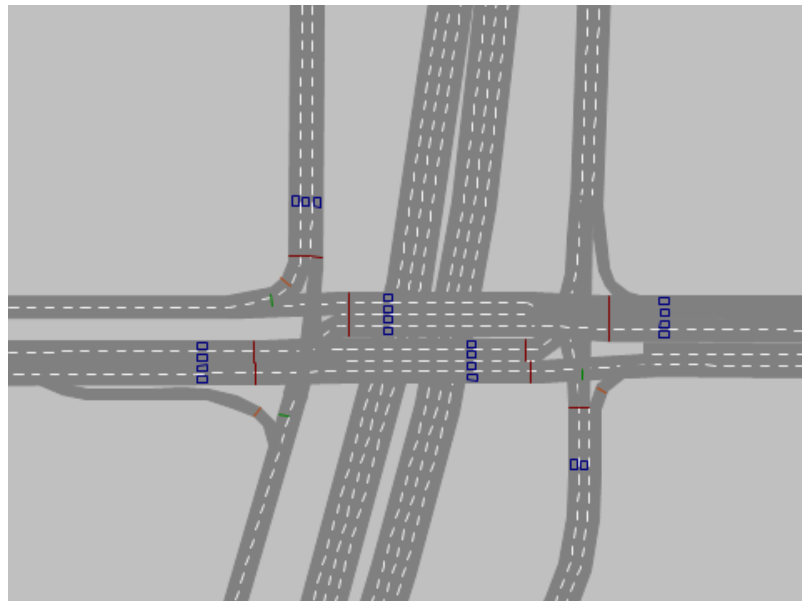


Figure 5. Layout of TDI in VISSIM

CHAPTER 4 MODEL CALIBRATION AND VALIDATION

Before the operation efficiency analysis, the calibration process is the prerequisite. In this study, the PM peak hour volume was employed into the calibration analysis as indicated in Table 1. Speed was selected for calibration and queue length for validation. The results are compared with the field observation to illustrate how coherently the simulation model duplicates field conditions and accordingly calibrates the model parameters. In this network, 12 static vehicle routes were used as indicated in Figure 6. In this figure, four origins and four destinations can be seen. In order to get more consistent results, the multiple simulation runs were used in the calibration process.

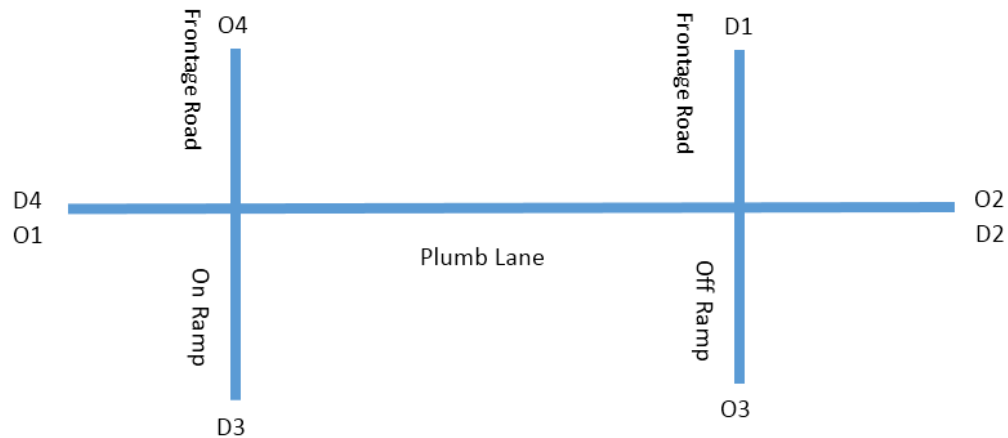


Figure 6. Static Origins and Destinations

Table 1. OD Matrix of the PM Observation Results

O/D	D1	D2	D3	D4	Total O
O1	820	326	631	0	1777
O2	121	0	233	319	673
O3	31	169	0	250	450
O4	0	64	95	610	769
Total D	972	559	959	1179	3669

4.1 Speed Calibration

Since the actual vehicle speed is significantly lower than the speed limit in this area, speed calibration was therefore needed in this research. The average speed was required to be evaluated through the field data collection. The procedure was to do multiple field-driving tests to extract the speed interval. For each route, average speed of six tests was used for the driving speed. Then, the highest speed (27 mph) and the lowest speed (16 mph) during the driving tests were chosen as the boundary of the speed interval. In this simulation, in case of the unbalanced distribution of speed, all the directions were following the same speed distribution.

4.2 Maximum Queue Length Validation

Besides the calibration for speed, the vehicle maximum queue length was also selected for validation. Multiple simulations were employed in the calibration for maximum queue length in order to minimize the fluctuation of the maximum queue length. In this section, the accuracy of the maximum queue length was evaluated. Ten simulations with different random speeds were taken into consideration. In the calibration process, the one-hour simulation was evenly divided into 12 intervals (5 min intervals). For each time simulation, the maximum queues of four critical movements for each direction and each interval were collected. The four critical movements were eastbound left turn movement (EBL), westbound left turn movement (WBL), southbound right turn movement (SBR), and northbound left turn movement (NBL). Figure 7 shows the average queue counts for each interval of EBL movement.

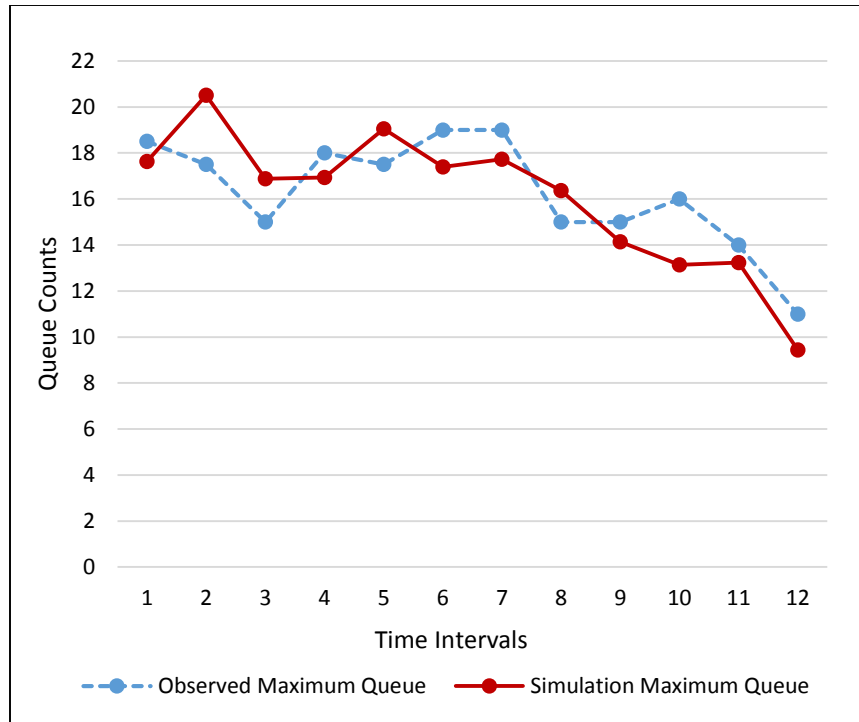


Figure 7. The Trend Variation of EBL Maximum Queue

From the chart, it can be seen that there is still some variation between the field data and the simulation results. However, the maximum queue difference between the field data and the simulation data was less than three vehicles. That means that after the calibration, the results should be quite similar and consistent with the field observation. From the beginning of the line chart, the field queue number is around 18 to 19, and the simulation vehicle queue number is around 17 to 18. At the end of the line chart, the field queue number ends at around 12 and the simulated queue number ends at around 9 to 10. In the middle, although the simulation results are not following the field queue counts, they are still in an acceptable range. Therefore, the dots reflect the real conditions after the calibration.

SBR is the second heaviest traffic group. The variation of the field data and the simulation results were shown in Figure 8. The simulation results were very close to the observed results. For interval 1 to 4, they are attached coherently. For interval 5 to 12, the changes of the simulation

results did not exhibit the same scale as the field data. However, the trend of the field data changes from interval to interval and is well depicted in simulation data. Also, the largest variation between the results is less than three vehicles. The SBR also presents reliable results as the EBL direction.

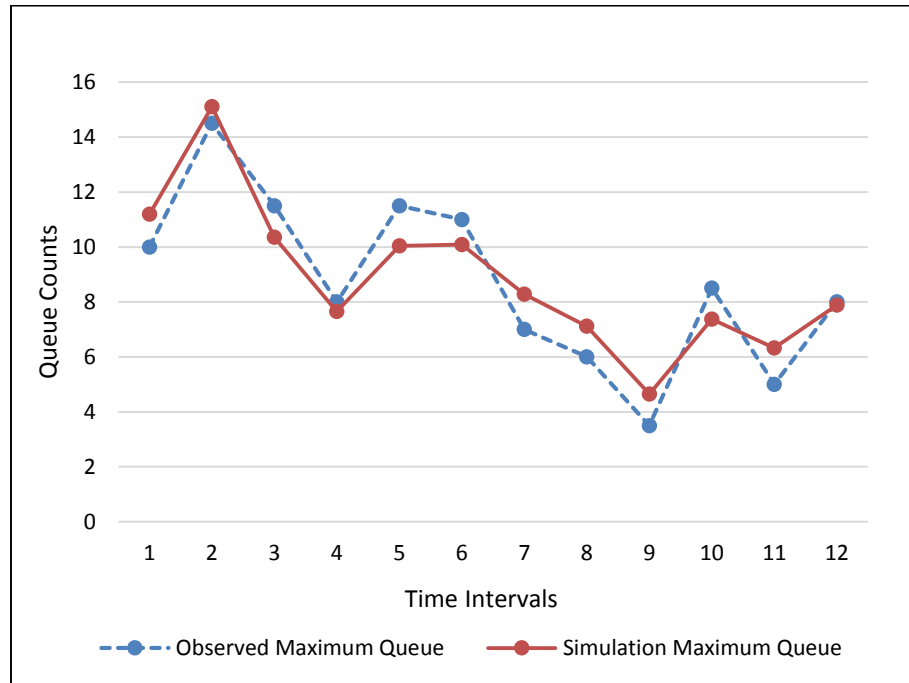


Figure 8. The Trend Variation of SBR Maximum Queue

The WBL approach is the critical group for the westbound direction. Because it is adjacent to the airport, the volumes by interval may have a sharp increase or decrease because of the departure or arrival times of the flights. From Figure 9, interval 5 has the supreme volume of all the intervals. The simulation results kept continuously tracing the field data. It can also be seen that the simulation for the last four intervals did not catch the field data tightly. The results are still within the acceptable range and the variation is within three vehicles. This means that the WBL also reflects the field to some degree.

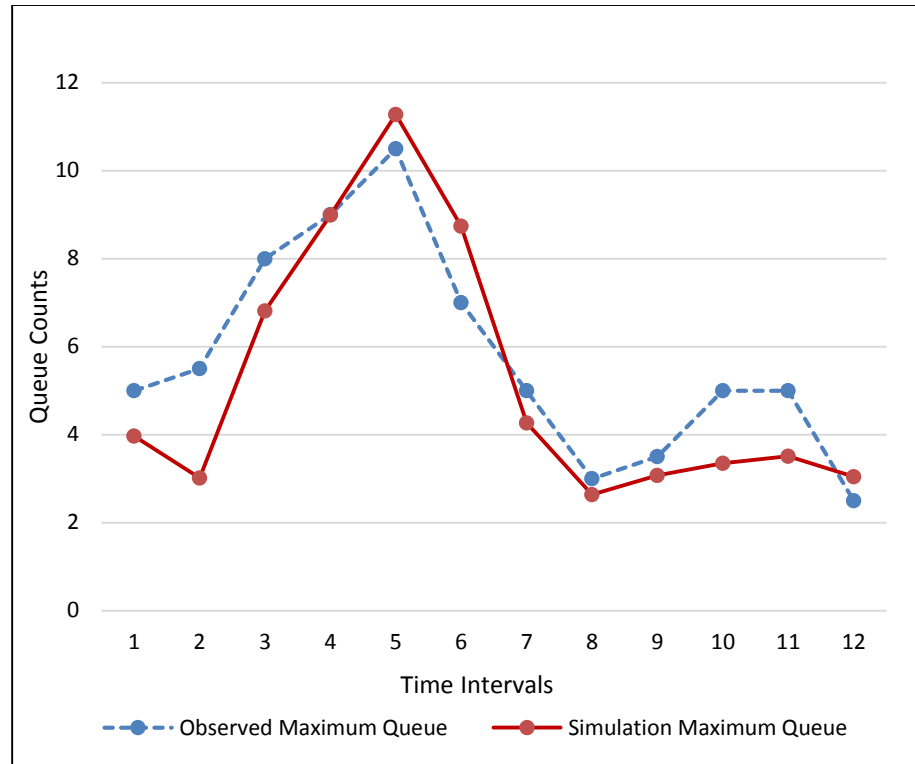


Figure 9. The Trend Variation of WBL Maximum Queue

The NBL approach queue variation details are demonstrated in Figure 10. The trend of the NBL queue variation is not as distinct as the previous three methods. From case 5 to case 12, there do not seem to be obvious changes with only a slight up and down fluctuation. Thus, the maximum simulation queue could not track the fluctuation effectively because of the uncertainty of the field traffic conditions and the predictability of the simulation data. From interval 2 to 4, there is a constant decrease towards the field queue counts. As it can be seen in the figure, the simulation data does suggest the real conditions.

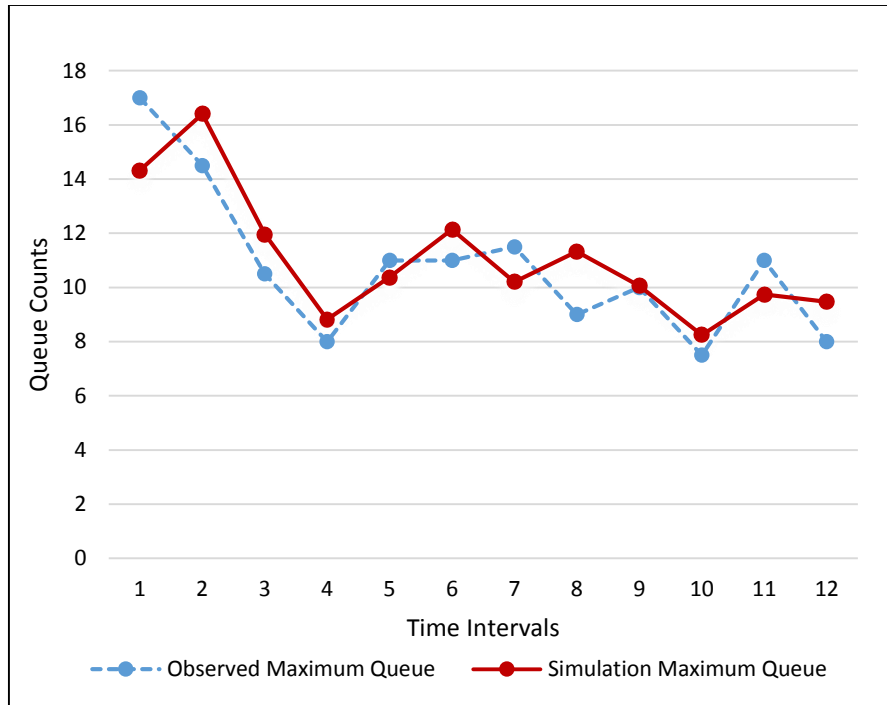


Figure 10. The Trend Variation of NBL Maximum Queue

The calibration process provided the firm relationship between the real world and the VISSIM model. The model can therefore produce reliable results as depicted in the field. There are still other problems however, like the lane change behavior being inconsistent with the real world. Also, the calibration just exhibited four critical movements from each direction, but the other factors did not significantly influence the average delay and other MOEs.

CHAPTER 5 EVALUATION METHODOLOGY OF TDI AND SPUI-F

This section will introduce the evaluation method, volume scenario design and the setting of the signal timing. Volume scenario details are provided and the details of signal timing parameters are introduced.

5.1 Evaluation Method

To exhibit reasonable comparisons results of both interchanges, different volumes were employed into the evaluation analysis. In this research, seven scenario groups were developed dedicated to this evaluation. Within the scenario groups, each group was divided into five cases to test the sensitivity analysis. A default volume for each scenario group expresses their characteristic as the group name indicated. Then, the adjustment of the default volume followed the criteria of +15% volume, +30% volume, -15% volume and -30% volume. The TDI geometry was designed based on the same outline of the SPUI. Same lane configurations were applied to both interchanges. During the simulations, the road network and the geometry were kept unchanged.

This research used PTV VISSIM microscopic simulation software to conduct the study. Real-time simulation and output MOEs were easily extracted through this software. Three MOEs were selected to perform the results of the simulation: average delay, average queue length, and average speed. Among them, the average delay was of significant importance. The average delay could reflect the operational efficiency. The average speed can support the results from the average delay. The average queue length could also reveal the operational efficiency and give confirmation to the conclusion from the average delay.

5.2 Volume Scenarios Design

The designed volume for this evaluation would not only reflect the current conditions but also offer scenarios to emphasize different cases. Thus, the base volume was designed based on the existing

volume. In this research, PM peak hour volume was selected as the default volume for base scenario. Besides the base scenario, six scenario groups were employed in the analysis as follows: heavy left turn movement scenario group, two approaches heavy left turn movement scenario group, heavy through movement scenario group, two approaches heavy through movement scenario group, heavy ramp scenario group, and two approaches heavy ramp scenario group.

Scenario groups introduction:

- **Base Scenario:** Derived from the PM peak hour existing volume with some of the numbers round up to the nearest two digits number.
- **Scenario 1 (one approach heavy left turn scenario):** Designed for evaluation of heavy left turn conditions. For this scenario, the eastbound left turn movement was increased.
- **Scenario 2 (two approaches heavy left turn scenario):** Based on the previous scenario, the left turn volume of westbound was also changed. It aims to test the both directions.
- **Scenario 3 (one approach heavy through scenario):** Designed for evaluating one heavy through movement.
- **Scenario 4 (two approaches heavy through scenario):** The aim of the scenario is similar to the previous one but both opposite approaches were tested.
- **Scenario 5 (one approach heavy ramp scenario):** Focused on how the ramp volume variations influence the evaluation results.
- **Scenario 6 (two approaches heavy ramps scenario):** Tested the double side of the ramp volume variations on the evaluation results.

For each scenario group, besides the default volume, the remaining four case volumes were changed by the fixed percentage of the default case. Table 2 illustrated the volume scenario groups.

Table 2. Volume Scenario Groups

		SBT	SBL	SBR	EBT	EBL	EBR	NBT	NBL	NBR	WBT	WBL	WBR	TOTAL
BASE SCENARIO	-30% Volume	77	28	420	175	560	490	21	336	140	210	196	42	2695
	-15% Volume	94	34	510	213	680	595	25	408	170	255	238	51	3273
	Default Case	110	40	600	250	800	700	30	480	200	300	280	60	3850
	+15% Volume	127	46	690	288	920	805	35	552	230	345	322	69	4429
	+30% Volume	143	52	780	325	1040	910	39	624	260	390	364	78	5005
SCENARIO 1	-30% Volume	77	28	420	175	700	490	21	336	140	210	196	42	2835
	-15% Volume	94	34	510	213	850	595	26	408	170	255	238	51	3444
	Default Case	110	40	600	250	1000	700	30	480	200	300	280	60	4050
	+15% Volume	127	46	690	288	1150	805	35	552	230	345	322	69	4659
	+30% Volume	143	52	780	325	1300	910	39	624	260	390	364	78	5265
SCENARIO 2	-30% Volume	77	28	420	175	700	490	21	336	140	210	280	42	2919
	-15% Volume	94	34	510	213	850	595	26	408	170	255	340	51	3546
	Default Case	110	40	600	250	1000	700	30	480	200	300	400	60	4170
	+15% Volume	127	46	690	288	1150	805	35	552	230	345	460	69	4797
	+30% Volume	143	52	780	325	1300	910	39	624	260	390	520	78	5421
SCENARIO 3	-30% Volume	77	28	420	280	560	490	21	336	140	210	196	42	2800
	-15% Volume	93.5	34	510	340	680	595	25.5	408	170	255	238	51	3400
	Default Case	110	40	600	400	800	700	30	480	200	300	280	60	4000
	+15% Volume	126.5	46	690	460	920	805	34.5	552	230	345	322	69	4600
	+30% Volume	143	52	780	520	1040	910	39	624	260	390	364	78	5200
SCENARIO 4	-30% Volume	77	28	420	280	560	490	21	336	140	315	196	42	2905
	-15% Volume	93.5	34	510	340	680	595	25.5	408	170	382.5	238	51	3527.5
	Default Case	110	40	600	400	800	700	30	480	200	450	280	60	4150
	+15% Volume	126.5	46	690	460	920	805	34.5	552	230	517.5	322	69	4772.5
	+30% Volume	143	52	780	520	1040	910	39	624	260	585	364	78	5395
SCENARIO 5	-30% Volume	126	70	560	175	560	490	21	336	140	210	196	42	2926
	-15% Volume	153	85	680	213	680	595	26	408	170	255	238	51	3554
	Default Case	180	100	800	250	800	700	30	480	200	300	280	60	4180
	+15% Volume	207	115	920	288	920	805	35	552	230	345	322	69	4808
	+30% Volume	234	130	1040	325	1040	910	39	624	260	390	364	78	5434
SCENARIO 6	-30% Volume	126	70	560	175	560	490	56	420	210	210	196	42	3115
	-15% Volume	153	85	680	212.5	680	595	68	510	255	255	238	51	3782.5
	Default Case	180	100	800	250	800	700	80	600	300	300	280	60	4450
	+15% Volume	207	115	920	287.5	920	805	92	690	345	345	322	69	5117.5
	+30% Volume	234	130	1040	325	1040	910	104	780	390	390	364	78	5785

5.3 Signal Operation Setting

The signal operation setting was the most important part in the evaluation. Both interchanges have their different characteristics. Thus, the timing designs of both interchanges need to show their advantages. The basic timing parameters were the prerequisite to timing designs. They included minimum green, vehicle extension time, yellow, red clearance and phase recalls. Since the aim of the research is to test the operational efficiency, the pedestrian walk time and clear time are not involved in the analysis.

As for the basic timing parameters, both interchanges have the same minimum green time and vehicle extension interval in order to minimize the variables in the evaluation. Also, these values were adopted from the current interchange. The detail timing parameters setting of SPUI-F and TDI are individually shown in Figure 11 and Figure 12.

Basic								
SG Number	1	2	3	4			7	8
SG Name								
Min Green	6	6	6	6			6	6
Veh Extension	3	3	3	3			3	3
Max 1	30	45	37	33			64	30
Yellow	3	3	3	3			3	3
Red Clearance	3	8	7	8			7	8
Ped SG Number								
Walk								
Ped Clear (FDW)								
Start Up	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Min Recall	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Max Recall	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Figure 11. SPUI-F Basic Timing

Basic								
SG Number	1	2	4	5	6	8	12	16
SG Name								
Min Green	6	6	6	6	6	6	9	9
Veh Extension	3	3	3	3	3	3		
Max 1	39	21	24	42	20	23	9	9
Yellow	3	3	3	3	3	3		
Red Clearance	3	2	4	3	2	5		
▶ Ped SG Number								
Walk								
Ped Clear (FDW)								
Start Up	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Min Recall	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Max Recall	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Figure 12. TDI Basic Timing

From the figures, it can be seen that the minimum green and vehicle extension of both interchanges were same. For the Yellow and Red Clearance interval there was a difference, since the widths of the two intersections are different. The Yellow and Red Clearance interval should meet the needs of each interchange. From the simulation and the field data, they were calculated as the figures indicate. As for the Min Recall and Max Recall, SPUI-F's max recall is set to coordinated phases, which are phases 4 and 8. For TDI, the operational strategy enrolled in the analysis is the TTI four phase. Thus, phases 1, 2, 5 and 6 were set with the Max Recall. Phases 12 and 16 are dummy phases, so they are always unchanged.

The optimal cycle length of each volume case has been calculated. According to Webster's method's guidance, an estimated optimal cycle length was derived. Then the cycle length range was expanded to the adjacent cycle length to locate the accurate one. A different cycle length may influence the average delay significantly. The tested increment of cycle length was 5 sec for every case. The aim of finding the optimal cycle length is to further decide the most appropriate timing

plan, which will be implemented in VISSIM and used for extraction of MOEs. Figures 13 and 14 show the cycle length trend line chart of the base scenario's default case as an example.

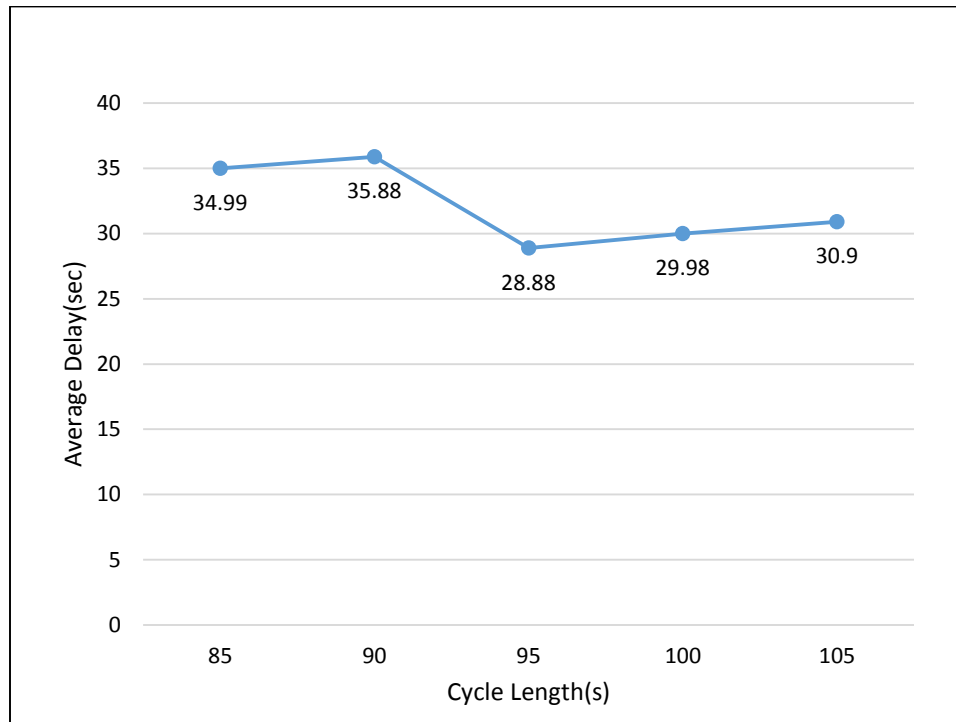


Figure 13. Cycle Length Trend of SPUI for Base Scenario's Default Case

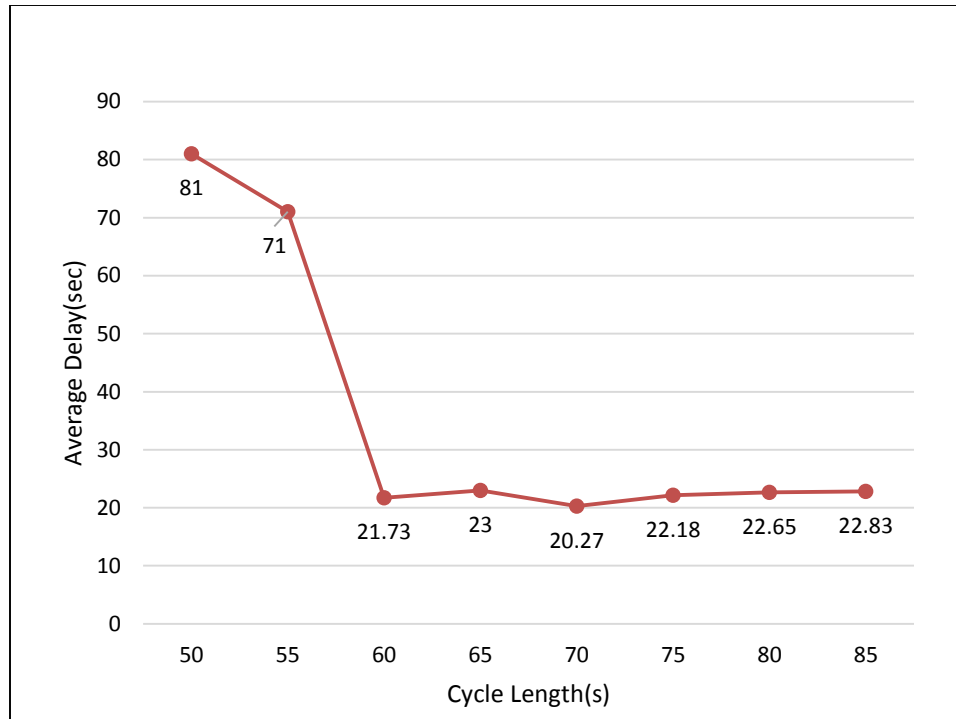


Figure 14. Cycle Length Trend of TDI for Base Scenario's Default Case

From Figure 13, the optimal cycle length of SPUI is 95 sec with an average delay of 28.88 sec. Figure 14 suggests that the optimal cycle length of TDI is 70 sec with an average delay of 20.27 sec. Thus, For SPUI, a longer cycle length was required under this case.

5.4 Phase Sequences and Overlaps

Apart from the basic timing parameters, the phase sequence and overlaps could influence the operational efficiency. Proper phase sequence and overlaps may maximize the capacity regard to particular approaches. Thus, to yield the better operational efficiency, the appropriate phase sequence and overlaps needs to be considered.

5.4.1 SPUI phase sequence

For SPUI-F, since there exists the frontage road, the three-phase control was not available for use. With this condition, an additional phase was used in order to implement the split phase, since phase

1 and phase 2 could not be arranged with overlaps because they are phases dedicated to ramps. However, for the cross street, it could be operated as either dual lead, lead-lag or dual lag phase sequence because eastbound or westbound movements have different phases individually for through movements and left turn movements. Since coordination is not adopted in the research, the phase sequence should not make changes to the evaluation results. For southbound right turn movement, it overlapped with phase 7 (eastbound left turn movement). It did not have the right of way when right turn on red because the double right turn lanes have conflicts with eastbound movements. Although the southbound right turn is not allowed right turn on red, the overlap would still expand the efficiency of the movement. The phase arrangement and sequence for SPUI-F are shown in Figure 15.

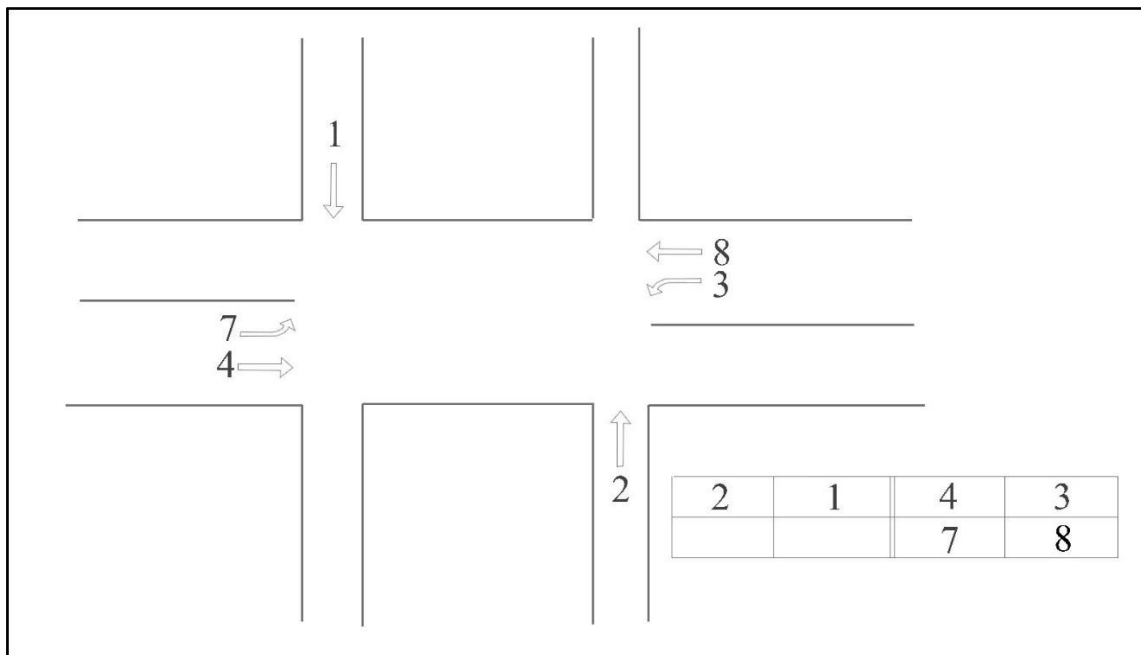


Figure 15. SPUI-F Phase Arrangement and Sequence

5.4.2 TDI phase sequence

For TDI operation, the TTI-four phase was used in this research because of the lack of storage in the middle. However, even if there was storage in the middle, the three phase control could not

support such a heavy volume. Thus, TTI-four phase was employed in the study, as it is currently one of the most efficient strategies. For overlaps, TDI has more overlaps than SPUI. Some of the overlaps are because of the road geometry and some of the overlaps are because of the TTI four phase. As Figure 16 indicates, the internal through movements have an overlap of the opposite through movements and internal left turn movements; this overlap is because of the road geometry. Phase 12 and phase 16 were dummy phases, which would operate to overlap the ramps and the through movements as indicated in Figure 16. This overlap is an attribute of TTI-four phase, which is also the reason why it has more efficiency.

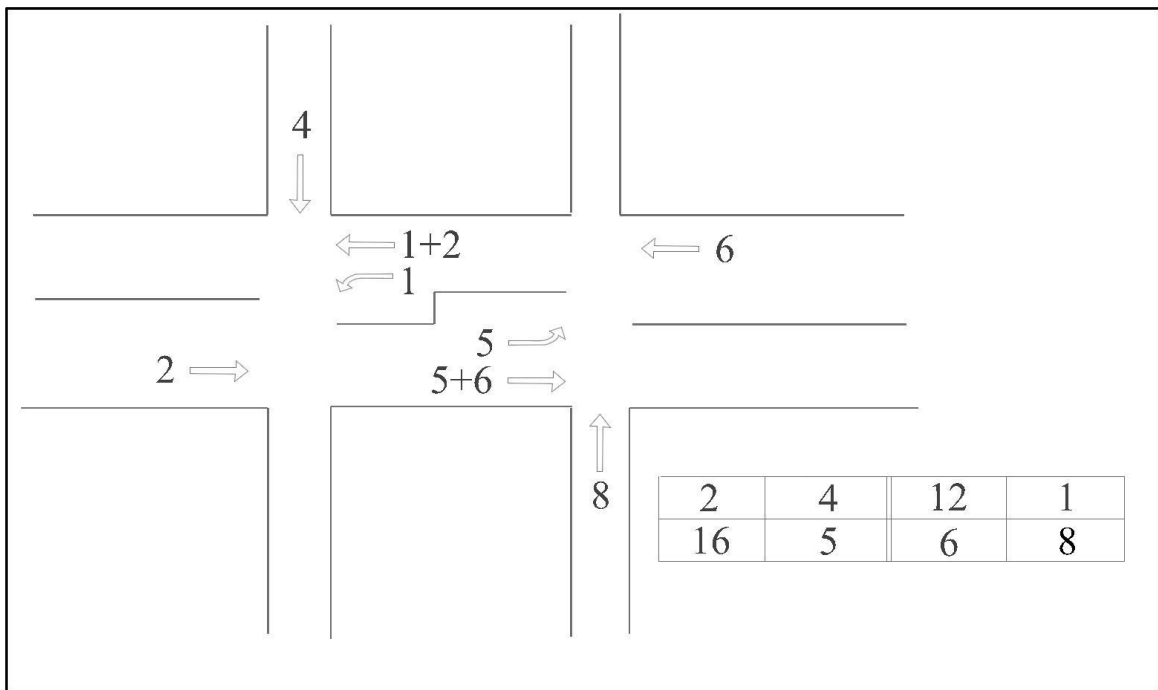


Figure 16. TDI Phase Arrangement and Sequence

5.5 Simulation Parameters

For the simulation of each volume case, a total of 3900-sec simulation interval was used. The first 300 sec does not account for the records because it was set as the warm up time. Multiple random

speeds were used in the continuous simulations. For each case, 10 simulations with different random speeds were input in the analysis in order to eliminate the fluctuation of results.

CHAPTER 6 EVALUATION RESULTS AND ANALYSIS

This chapter will introduce the evaluation results for different scenario groups. Each scenario group will be organized accordingly, and three MOEs will be explained to express the results. In those figures, the name of SPUI indicates the SPUI-F.

6.1 Base Scenario Group

The base scenario group is the one which most conforms to the reality. Evaluation results from this scenario would not only provide evidence for the general conclusion towards the evaluation but also reinforce the current timing operation. Figure 17 exhibited the average delay of the base scenario group. Figure 18 summarizes the average speed for different volume cases. Average queue length is summarized in Figure 19.

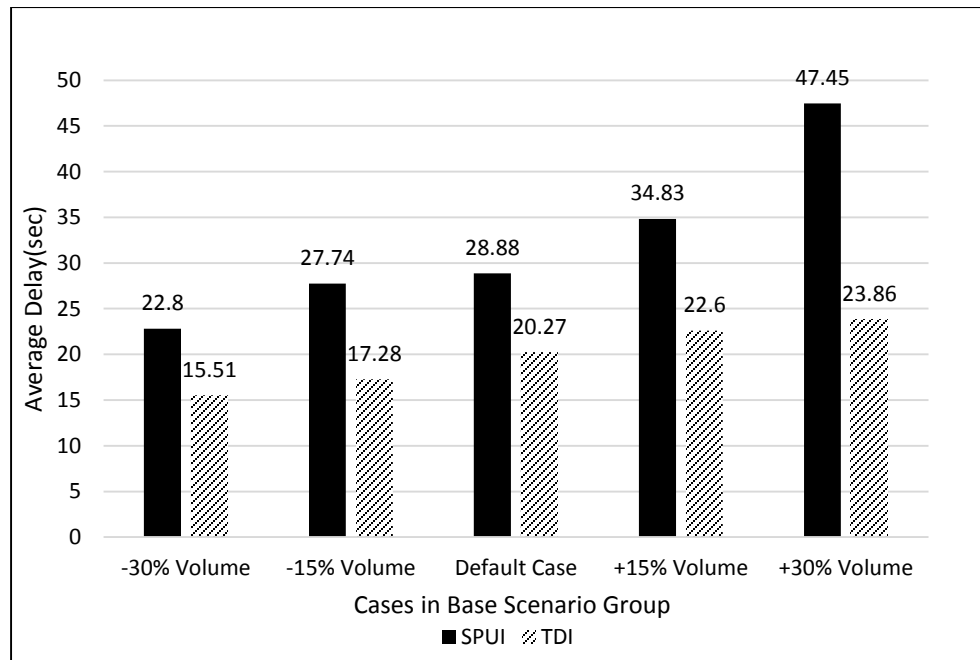


Figure 17. Average Delay for Base Scenario Group

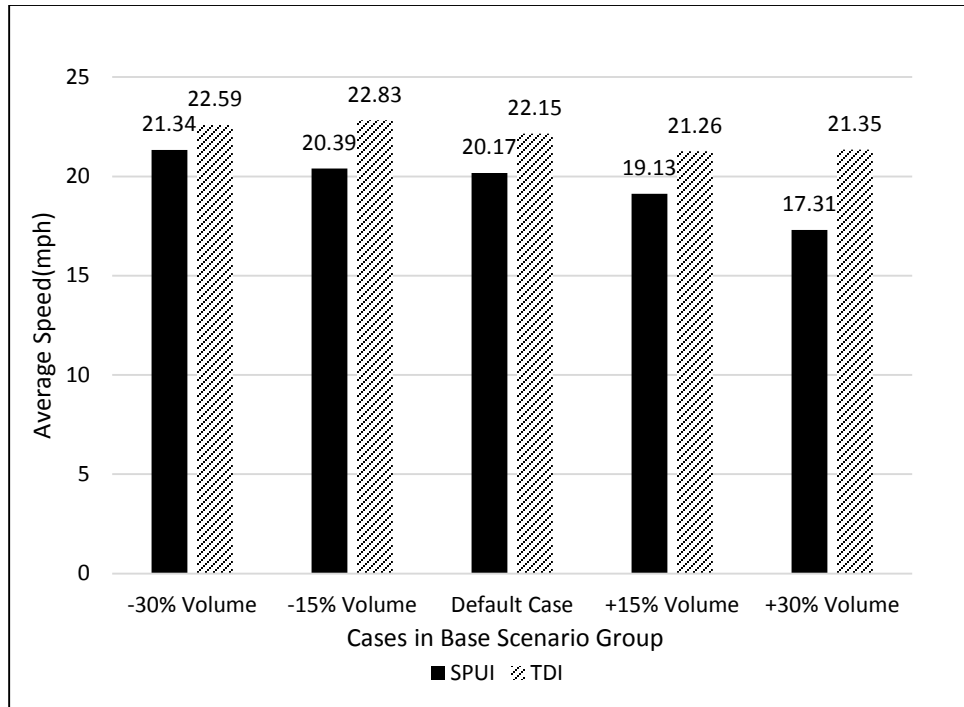


Figure 18. Average Speed for Base Scenario Group

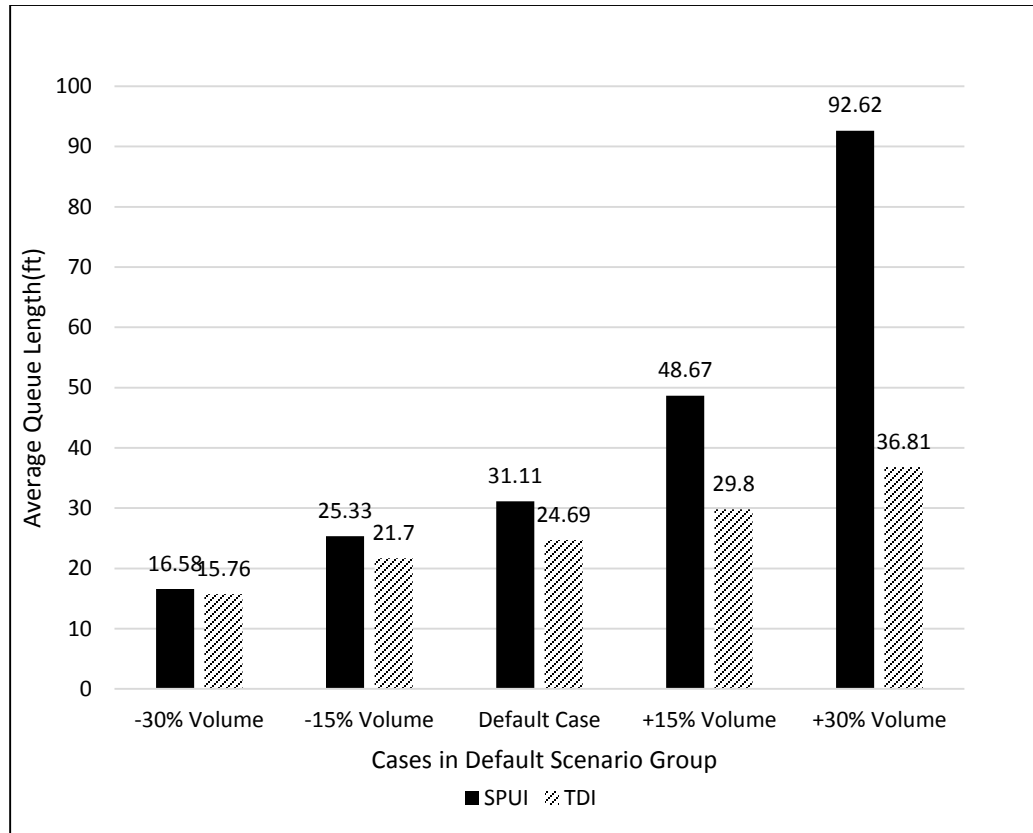


Figure 19. Average Queue Length for Base Scenario Group

From Figure 17, the TDI outperformed SPUI-F in every volume case. For SPUI, the increment of average delay between the volume cases was much more significant than TDI. Furthermore, it could be calculated that the average delay range for the SPUI is 24.7 sec while for TDI it is 8.35 sec. That indicates the operational efficiency of SPUI-F is more sensitive to the volume changes when compared to TDI under this scenario group. In other words, TDI is much more reliable. Figure 18 exhibits the average speed according to the volume cases. The speed of five cases reinforced that TDI is more efficient than SPUI-F, which is certainly in line with the preference given by the average delay results. From Figure 18, the speed of TDI is higher than SPUI-F for each volume case. Also, the speed of SPUI-F decreases significantly when the volume is increasing. However, the TDI does not have a big drop. The speed range of SPUI-F is 4.03 mph, while TDI it is only 1.48 mph. As for the queue length, with increasing volume, both SPUI-F and

TDI have the growth of average queue length, but from the lowest volume case to the highest volume case, the average queue length range for SPUI-F is 76.04ft, and in contrast, the value for TDI is 21.05ft. When volume is increasing, the queue length of SPUI is increasing rapidly converse to TDI. Overall, for the default scenario group, the TDI outperformed SPUI-F in operational efficiency.

6.2 Scenario 1 (One Approach Heavy Left Turn Scenario Group)

Scenario 1 involved five cases with different volumes from low to high. This scenario group aims to simulate when left turn volume is greater than normal for each case. Thus, EBL movement volume was greatly enhanced. Figure 20 suggests the trend of average delay changes to both interchanges and the detail values. Figure 21 demonstrates the average speed changes according to different volumes. Figure 22 illustrates the average queue length details of this scenario group.

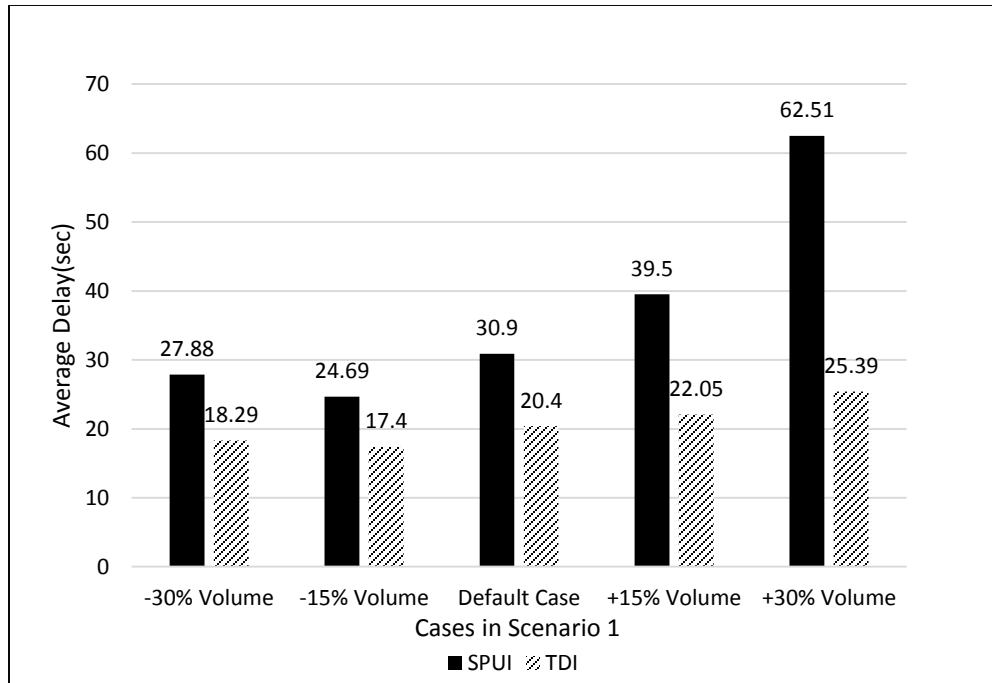


Figure 20. Average Delay of Scenario 1

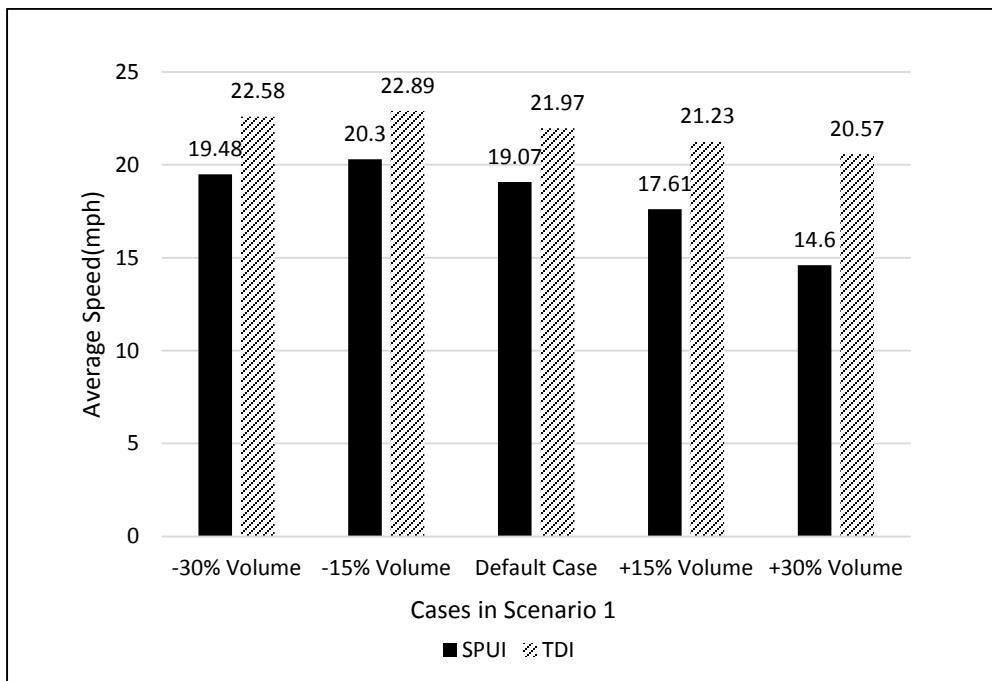


Figure 21. Average Speed of Scenario 1

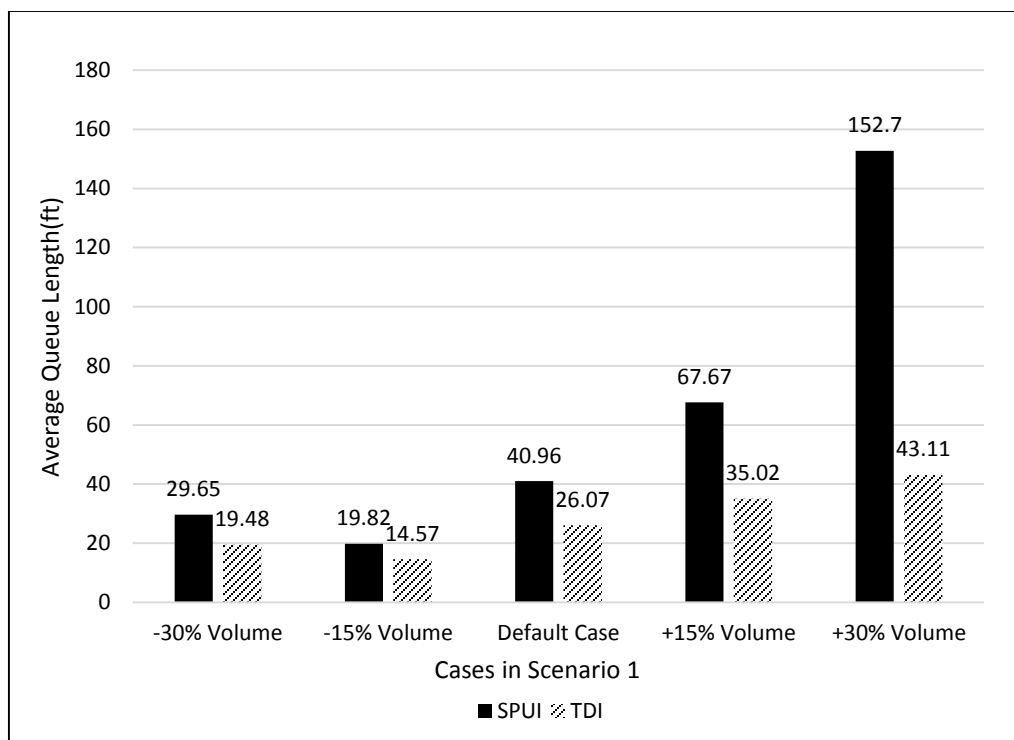


Figure 22. Average Queue Length of Scenario 1

Figure 20 illustrated that for all the cases in scenario 1, the TDI outperformed SPUI-F. For SPUI-F, the case with the lowest volume is not the one with the lowest average delay; the -15% volume cases held the lowest average delay. In response to this, the average delay of TDI had the same condition. Even with this pattern, the average delay range of TDI is still less than SPUI-F significantly. It is easy to calculate that the average delay range of SPUI-F is 37.82 sec and the range of TDI is 7.99 sec. The highest average delay of SPUI-F is 62.51 sec, but for the TDI it is only 25.39 sec. It could be concluded that not only does the TDI has greater stability but also has the lower delays. Figure 21 supported the conclusion from average delay in an opposite view. The lower average delay reflected the higher speed. Thus, from Figure 21, the lowest average speed of all cases for TDI is 20.57 mph while the highest average speed for SPUI-F is 20.3 mph. Thus, the TDI's priority is greatly enhanced by speed comparison. As for the average queue length, it is consistent with the average delay. For every case, the SPUI-F had a longer average queue length

than TDI. For the +30% volume case, the difference between the two interchanges is 109.59 ft. That might indicate that for oversaturation conditions, the TDI may save more time than SPUI-F. In sum, for one approach heavy left turn scenario group, TDI still outperformed SPUI-F.

6.3 Scenario 2 (Two Approaches Heavy Left Turn Scenario Group)

Both EBL and WBL were greatly enhanced by volumes in the scenario 2. Although it did not reach the balance condition for both enhanced approaches, the volume condition significantly changed compared to scenario 2. Figure 23 presents the average delay of each case for Scenario 2. The average speed details are indicated in Figure 24. Figure 25 demonstrates the comparison of average queue length for each case.

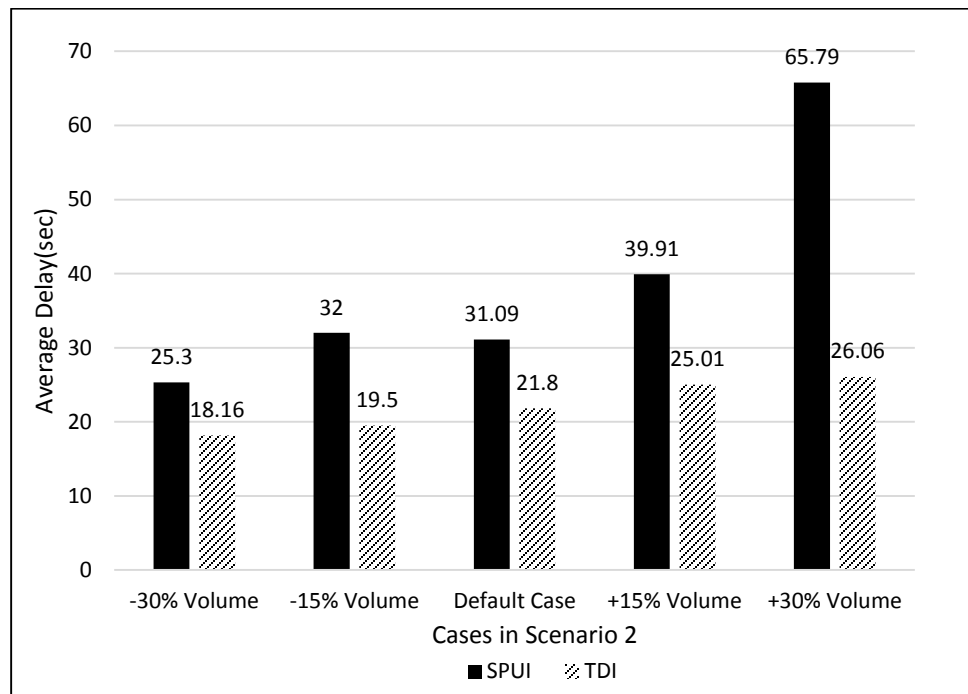


Figure 23. Average Delay of Scenario 2

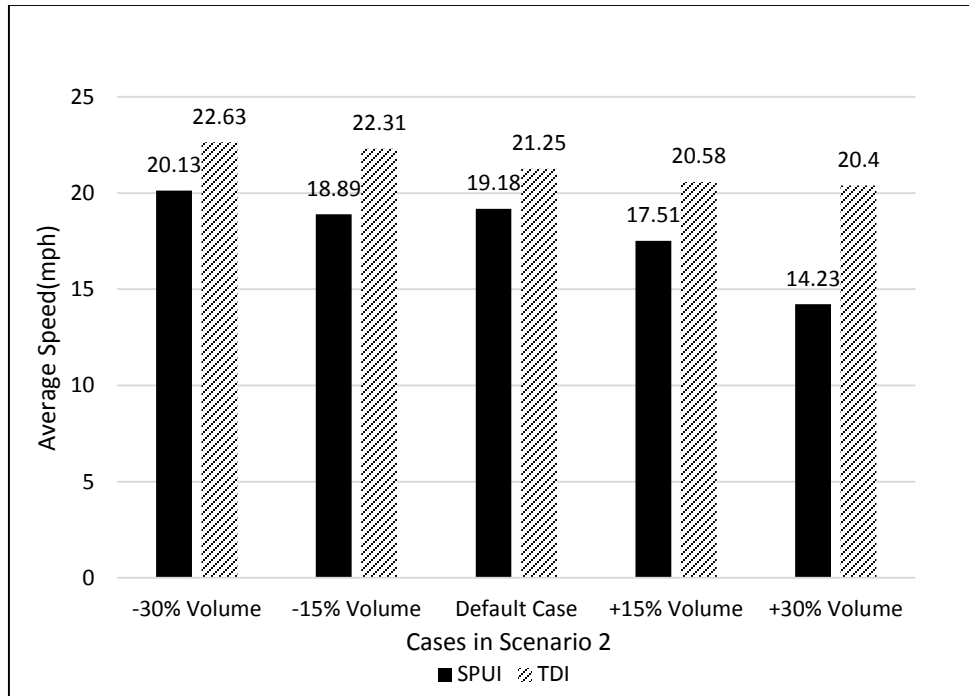


Figure 24. Average Speed of Scenario 2

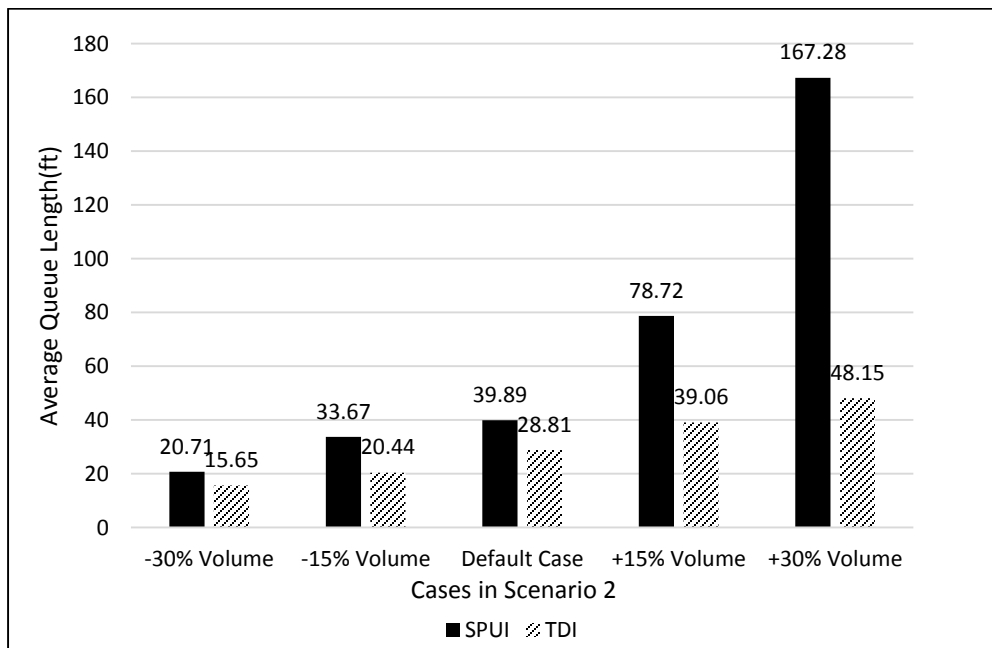


Figure 25. Average Queue Length of Scenario 2

Figure 23 shows that both of the alternatives roughly had equal increase in average delay and volume except for the -15% volume case. For all five cases, the average delay of SPUI-F is larger than TDI, which means the TDI still outperformed SPUI-F. The range of SPUI-F is 40.49 sec, and the range for TDI is 7.9 sec which indicates that the TDI is more reliable than SPUI-F when subjected to the heavy volume. Also from Figure 24, the TDI's lowest speed of all cases is 20.6 mph while for SPUI-F the highest speed is 20.13 mph, which greatly enhanced the TDI's preference. The range of speed for TDI is 2.23 mph, and in contrast, the range of speed for SPUI-F is 5.9 mph, which still enhanced the reliability of TDI. The evaluation towards average queue length is consistent with average delay. In Figure 25, the average queue length of SPUI-F increased rapidly from 20.71ft up to 167.28ft. While for TDI, the average queue length increases from 15.65ft to 48.15ft, which appears to be more stable and lower than SPUI-F. Therefore, the values from average queue length support the conclusion in a positive way. Overall, the TDI still has the priority.

6.4 Scenario 3 (One Approach Heavy through Scenario Group)

After discussing the conditions of heavy left turn volume, the scenario 3 is going to be evaluated. Through movement is very important in reality because usually, the coordination phase would choose the through phases. Thus, testing the operational efficiency with heavy through volume will help the coordination. In this scenario group, the one approach through movement will be enhanced. Figure 26 illustrates the output information of average delay for each case. Figure 27 exhibits the output for speeds and their variation. Figure 28 indicates the average queue length for both interchanges.

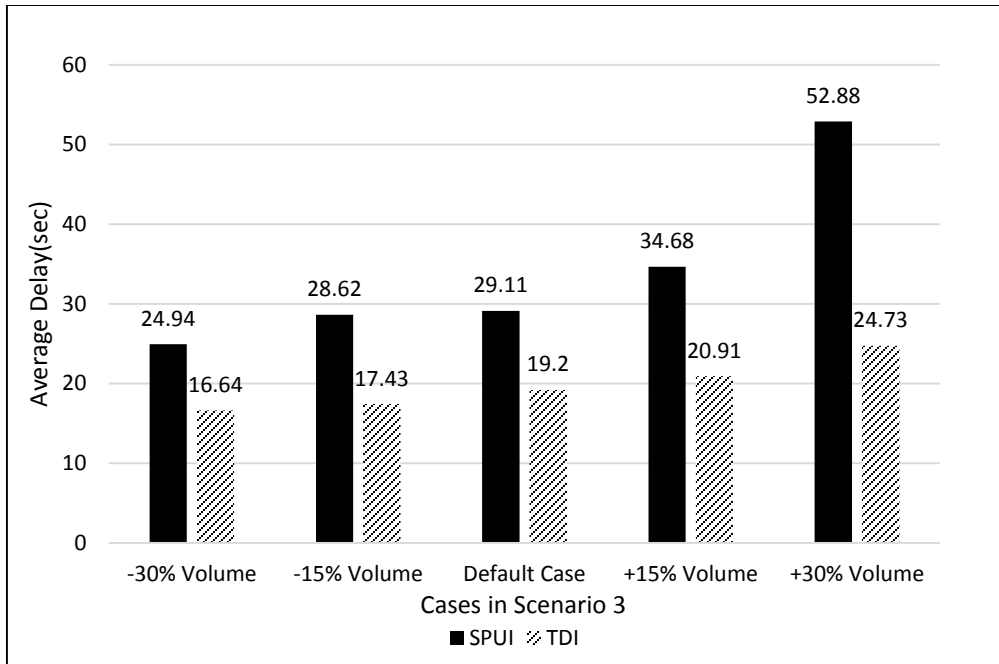


Figure 26. Average Delay of Scenario 3

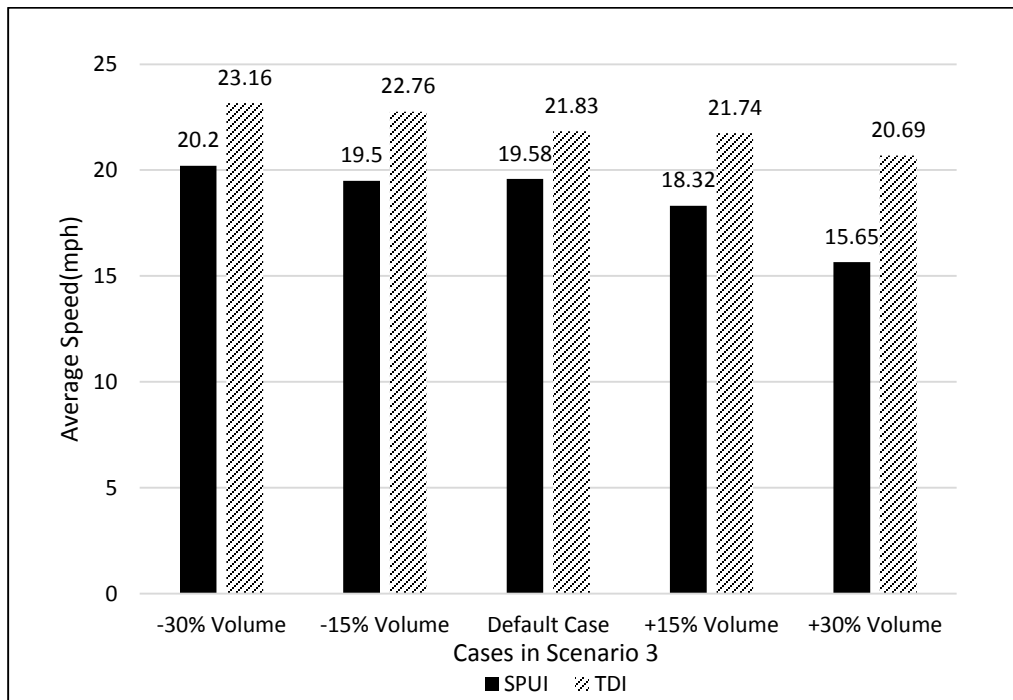


Figure 27. Average Speed of Scenario 3

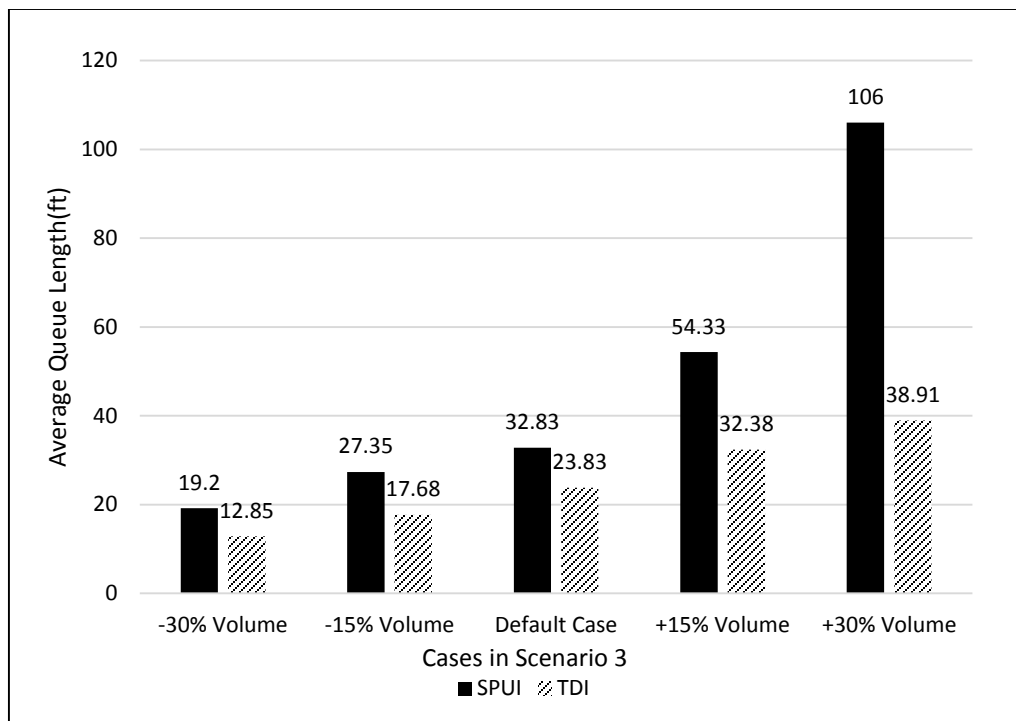


Figure 28. Average Queue Length of Scenario 3

It is obvious to see that for the average delay of all cases, the TDI still outperformed SPUI-F. The trend of the average delay for SPUI-F and TDI are both increasing according to the volume levels from low to high. However, the range of the two alternatives is different. It could be easily calculated that the range for SPUI-F is 27.94 sec and for TDI is 8.09 sec. The average delay variation for SPUI-F is three times more than TDI. Thus, for reliability, the TDI outperforms SPUI-F. The highest average delay for TDI among all cases is 24.73 sec while for SPUI-F the lowest average delay is 24.94 sec. That means the TDI will save much more time than SPUI-F. This is consistent with what speed indicates in Figure 27. Even the highest speed of SPUI-F (20.2 mph) could not reach the lowest speed of TDI (20.69 mph) in the group, which means the TDI will improve the speed vehicle passing through the interchange, therefore, enhancing the operational efficiency. As for the average queue length, the increasing of it is much more significant when volume goes up. Average queue length for SPUI-F goes up from 19.2ft to 106 ft. In contrast, TDI

goes up from 12.85ft to 38.91 ft. With this value, it could be inferred that TDI would not have too much queue increase when the volume is high. Overall, for one approach heavy left through scenario group, the TDI outperforms SPUI-F.

6.5 Scenario 4 (Two Approaches Heavy through Scenario Group)

The motivation of designing scenario 4 aims to test the operational efficiency when both sides of through volumes are high. Consistent with the previous two approach heavy left turn scenario group, both approaches were enhanced but they were still not balanced. Figure 29 demonstrates the output average delay conditions for all cases. Figure 30 suggests the speed variation between the two alternatives. The average queue length is extracted in Figure 31.

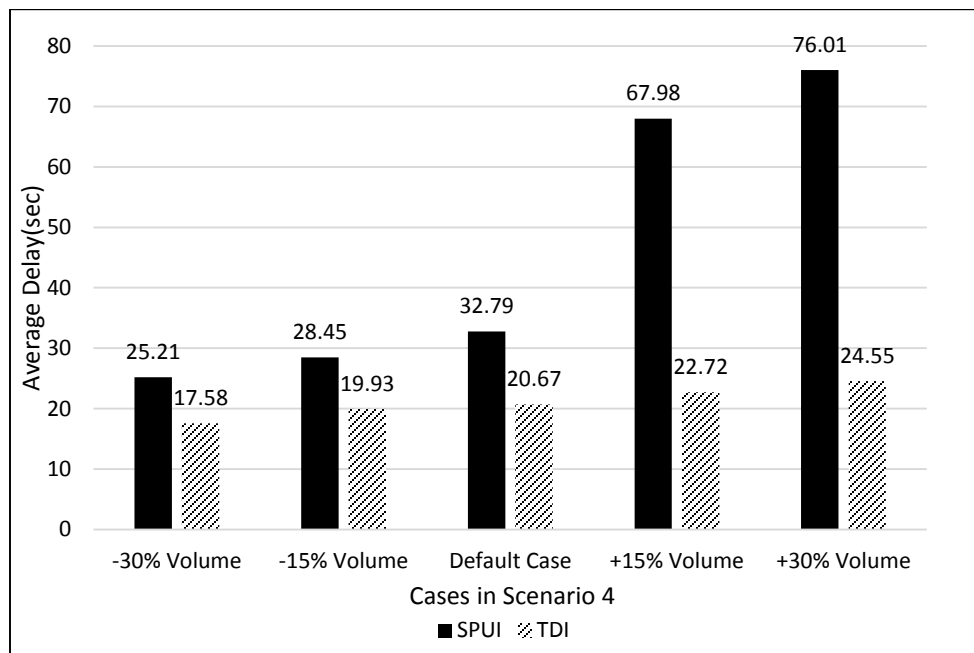


Figure 29. Average Delay of Scenario 4

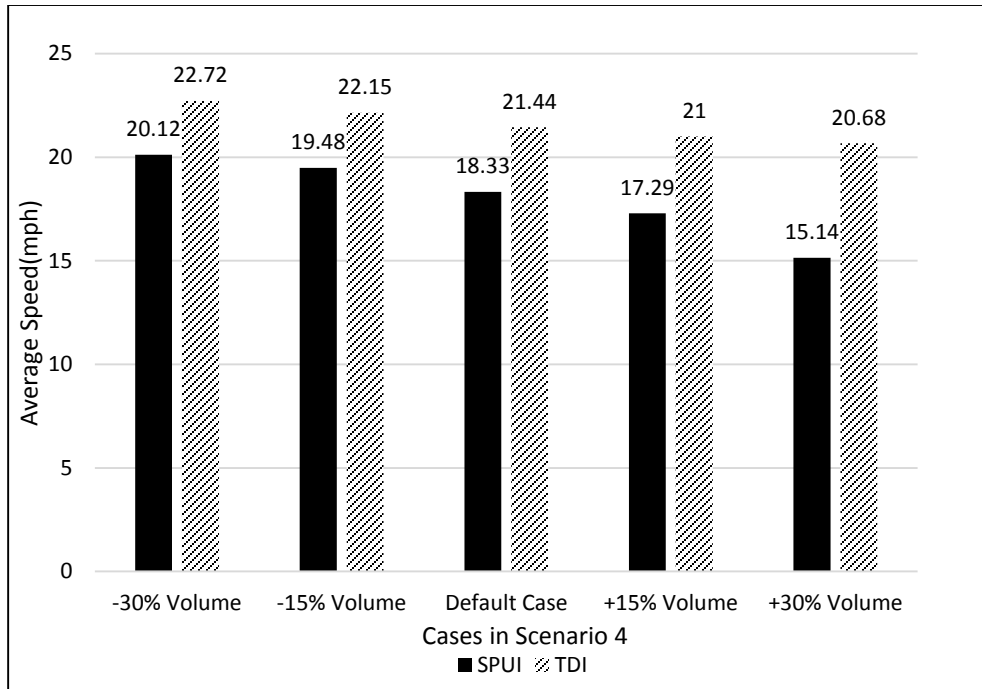


Figure 30. Average Speed of Scenario 4

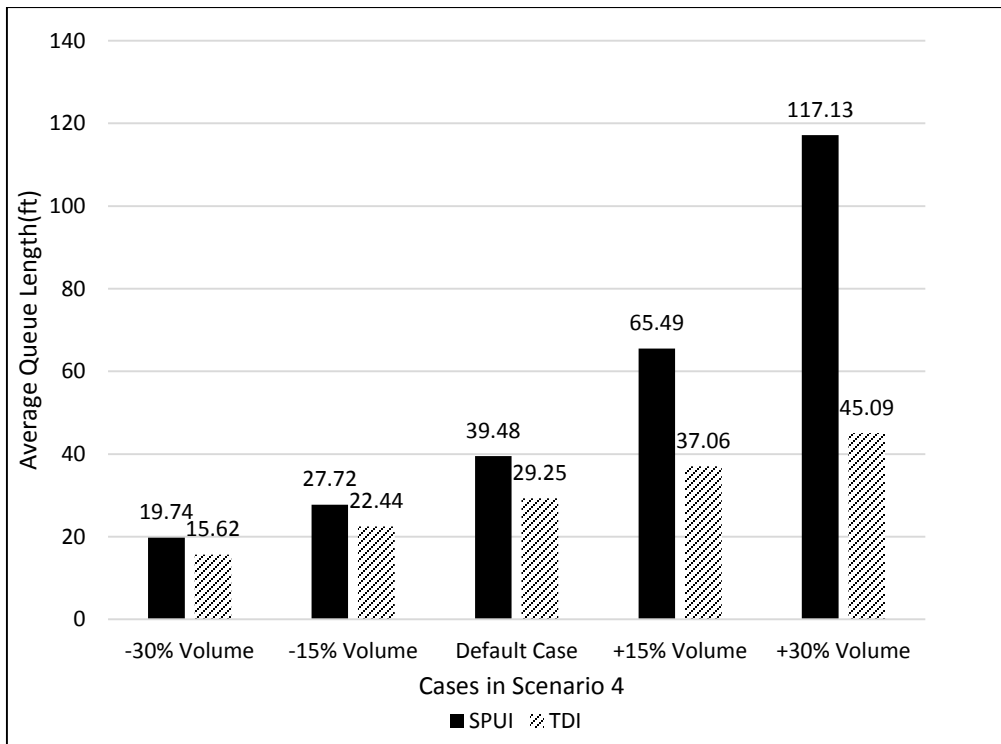


Figure 31. Average Queue Length of Scenario 4

In Figure 29, TDI outperformed SPUI-F in every case for the average delay. For the first three volume cases, SPUI-F did not have too many variations, but for the last two volume scenarios, the SPUI-F's average delay increased rapidly from 32.79 sec to 67.98 sec. The increase of average delay for TDI smoothly kept the same pace. The range for SPUI-F is 50.8 sec and for TDI is 6.97 sec, which suggests the TDI is more trustworthy than SPUI-F. The average speed results greatly enhanced the TDI's priority. As indicated in Figure 30, the speed range for SPUI-F is calculated as 2.04 mph while for TDI it is 4.98 mph. It is consistent with the previous scenario where the speed results proved the TDI is preferred. As for the results of average queue length, the queue length range is 97.39ft with SPUI-F and 29.4ft with TDI. Thus, the reliability of TDI was reflected by the queue length. If TDI was employed in this scenario group, it might help to decrease queue length significantly. Overall, TDI is more popular when testing two approaches heavy through scenario group.

6.6 Scenario 5 (One Approach Heavy Ramp Scenario Group)

Apart from the scenarios enhancing the mainline volume, the ramps are as important as cross streets because ramps would directly influence the freeway, which may cause severe problems if congestion issues occur. This scenario aims to test operational efficiency of both interchanges when the heavy volume is applied to one side ramp. Figure 32 indicates that the average delay results for different cases belong to this scenario group. Figure 33 demonstrates the average speed variation towards the different volume levels. Figure 34 illustrates the average queue length results in regard to the different cases.

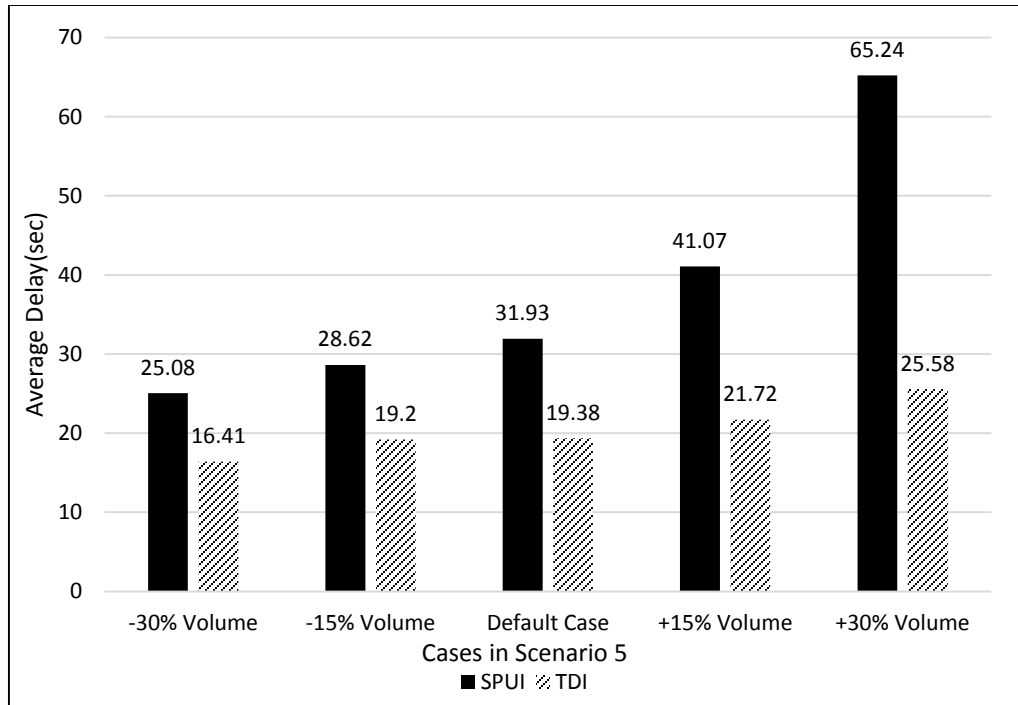


Figure 32. Average Delay of Scenario 5

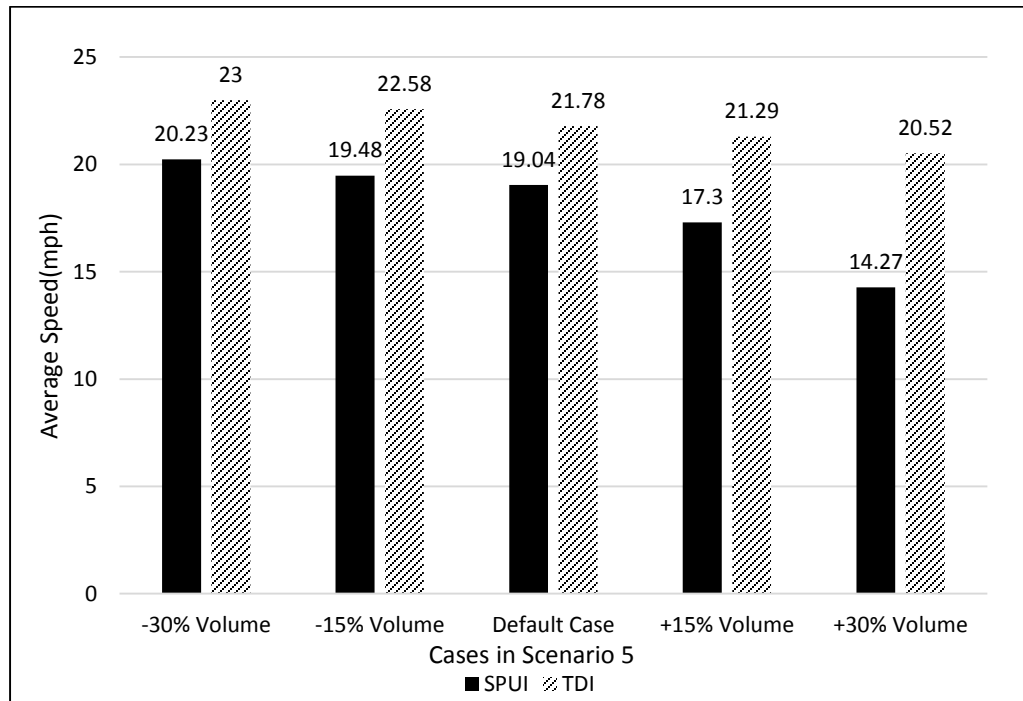


Figure 33. Average Speed of Scenario 5

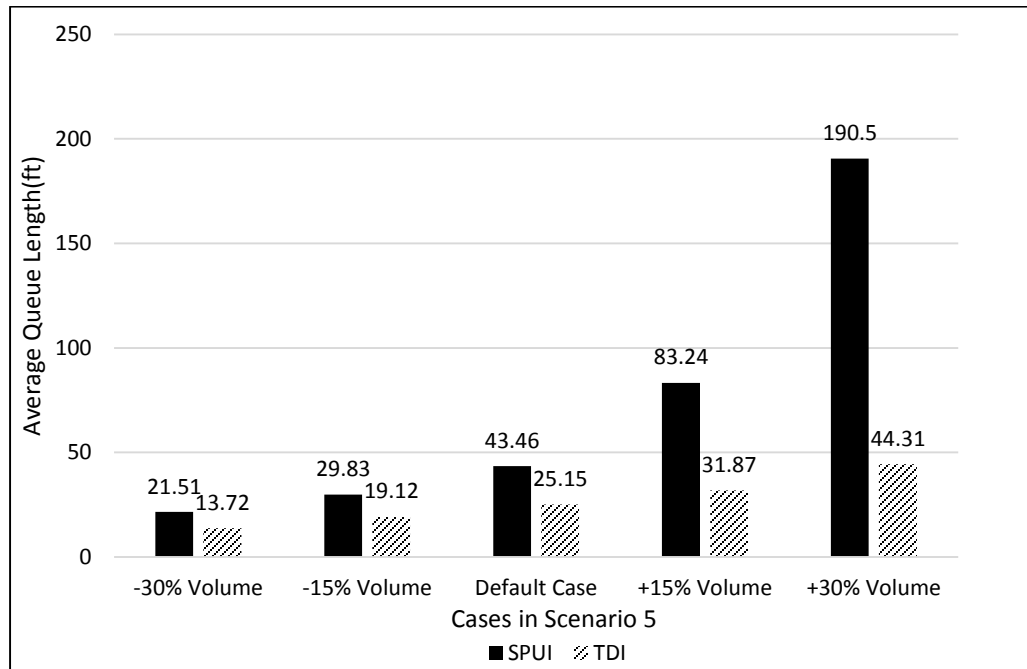


Figure 34. Average Queue Length of Scenario 5

Figure 32 concludes that both SPUI-F and TDI have the average delay increased when volume is increasing. However, the average delay range between the two alternatives is significantly different. The range of SPUI-F is 40.16 sec while for TDI the range is 9.17 sec. Thus, the TDI performed more stable than SPUI-F under this scenario group. Then, by looking at the values for each case, the TDI performed with a lower average delay than SPUI-F. Thus, TDI outperformed SPUI-F under this scenario. Other evidence like the average speed showed that the average speed tends to decrease. The average speed of TDI dropped from 23 mph to 20.52 mph and in contrast, the SPUI-F dropped from 20.23 mph to 14.27 mph. Two important details could be extracted from the figure: the highest speed of SPUI-F could not reach the lowest speed of TDI; the speed variations of SPUI-F are much larger than TDI. Thus, the TDI outperformed SPUI-F through the evaluation of the average speed. By analyzing the average queue length, the range of queue length for SPUI-F is from 21.51 ft to 190.5 ft. The range of TDI is only 30.59 ft. The span

of SPUI-F results was much more than TDI. Also for each case, the TDI had the shorter queue length than SPUI-F. Therefore, the TDI still outperformed SPUI-F.

6.7 Scenario 6 (Two Approach Heavy Ramp Scenario Group)

In this scenario, both ramps increased volumes. Inconsistent with the previous two scenarios, this scenario explores the operational efficiency of two ramps, but it is still an unbalanced condition. Figure 35 shows the average delay conditions of five volume levels. Figure 36 delineates the average speed variations to the different case. The average queue length details are demonstrated in Figure 37.

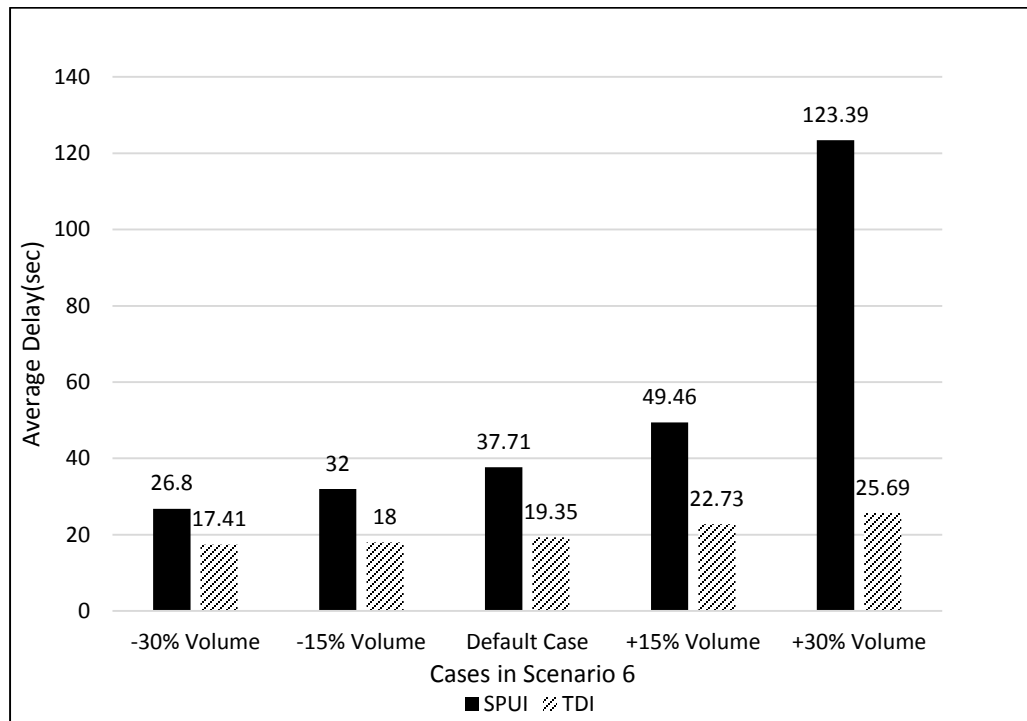


Figure 35. Average Delay of Scenario 6

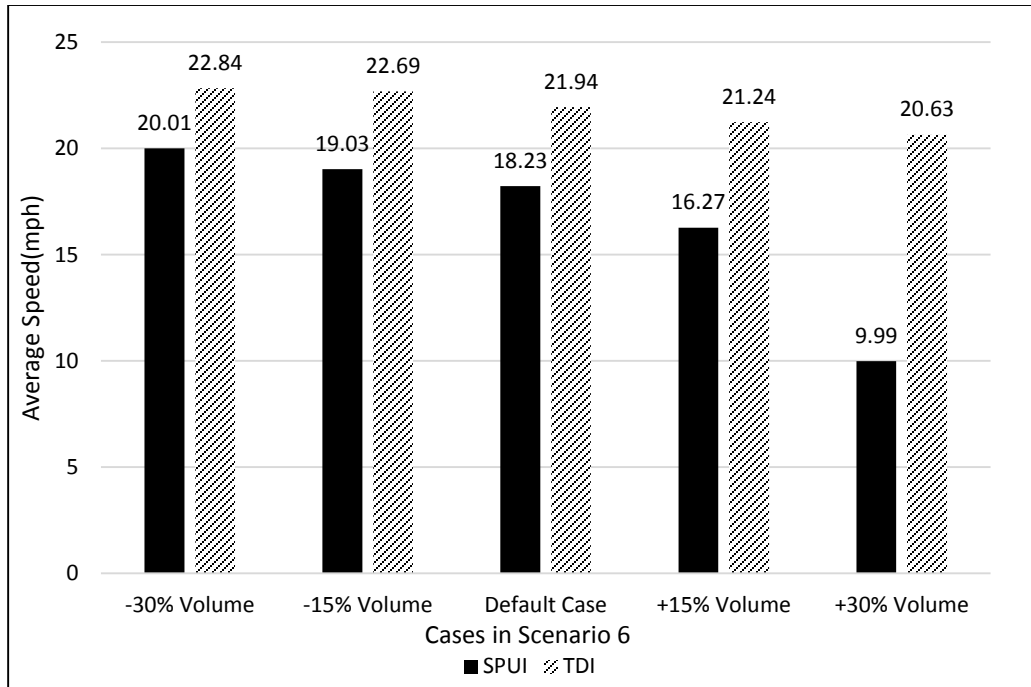


Figure 36. Average Speed of Scenario 6

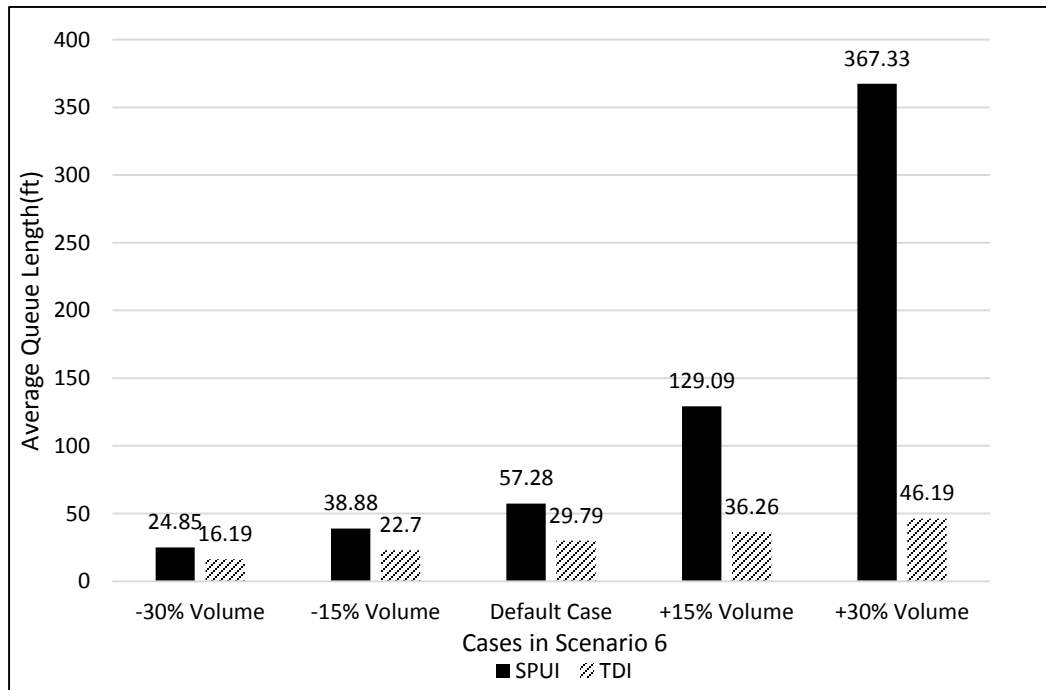


Figure 37. Average Queue Length of Scenario 6

From Figure 35, it can be seen that the average delay for SPUI-F experienced a sharp increase from 49.46 sec to 123.49 sec. It could be inferred that under the +30% volume case, the vehicles keeps accumulating. The average delay range of SPUI-F is 96.59 sec and for TDI the range kept within 10 sec. Therefore, SPUI-F could not be used under this condition but TDI still performed well. The speed variations reflect the results from average delay coherently. For the +30% volume case, the average speed for SPUI-F is 9.9 mph, and the average speed for TDI is 20.3 mph. The 9.9 mph might explain the uncommon delay in another way. The average speed range of TDI is 2.21 mph, and for SPUI-F the range is 10.02 mph. Thus, the TDI has more reliability. Furthermore, the lowest average speed of all cases for TDI is higher than the highest speed of all cases for SPUI-F. Thus, under this scenario, the TDI has the priority. By looking at the average queue length, the conclusion is consistent with the previous two MOEs. TDI kept the shorter average queue length in each case compared to SPUI-F. Thus, the priority of TDI was greatly enhanced. Overall, the TDI outperformed SPUI-F under this scenario group.

Chapter 7 Conclusion and Future Works

This research first introduced the SPUI-F and TDI. The motivation of the study was generated from the I-580/Plumb Lane interchange, which was first a TDI and in 2003 was changed to a SPUI-F. Many research evaluated the operational efficiency differences of the SPUI and TDI, but there was a lack of evaluation evidence for SPUI with a frontage road. Therefore, this research conducted a comparison evaluation specifically for the SPUI-F and TDI.

A comprehensive literature review was provided according to different categories. The operational features and application of SPUI were first introduced, followed by the operational features and application of TDI. It also summarized the previous studies dedicated to the safety and operation perspective. The shortcomings of existing research were introduced. The literature review clearly showed that there is a need for this study, since all previous research were focused on SPUI and not SPUI-F.

For comparison, a real case was selected and was modeled in VISSIM. The model then was calibrated based on speed and validated by queue length. Multiple simulations were applied during the calibration process. For four approaches, each of the approaches selected its critical movement into the calibration. Four major movements in simulation fitted the field condition well.

Seven scenarios were designed and applied to different cases. Five different volume levels from low to high were employed for each scenario. The left turn movements, through movements, and ramp movements were changed individually in each scenario. Three MOEs were selected: average delay, average speed, and average queue length. The average delay was the primary MOE factor while average speed supported the conclusions from average delay in the opposite view and the average queue length supported it directly.

Figure 38 summarizes the findings of the evaluation chapter. As it can be seen in this figure, the TDI outperformed SPUI-F for all the scenarios as indicated in Figure 38. However, if SPUI-F is implemented, the drivers do not necessarily stop in the middle, which is a big advantage when comparing with TDI. However, according to the data analysis, it could be seen that the TDI is more reliable according to the range analysis. SPUI-F seemed unreliable, especially in heavy volume cases. Another issue is that for the optimal cycle length, TDI appeared to be much shorter than SPUI-F.

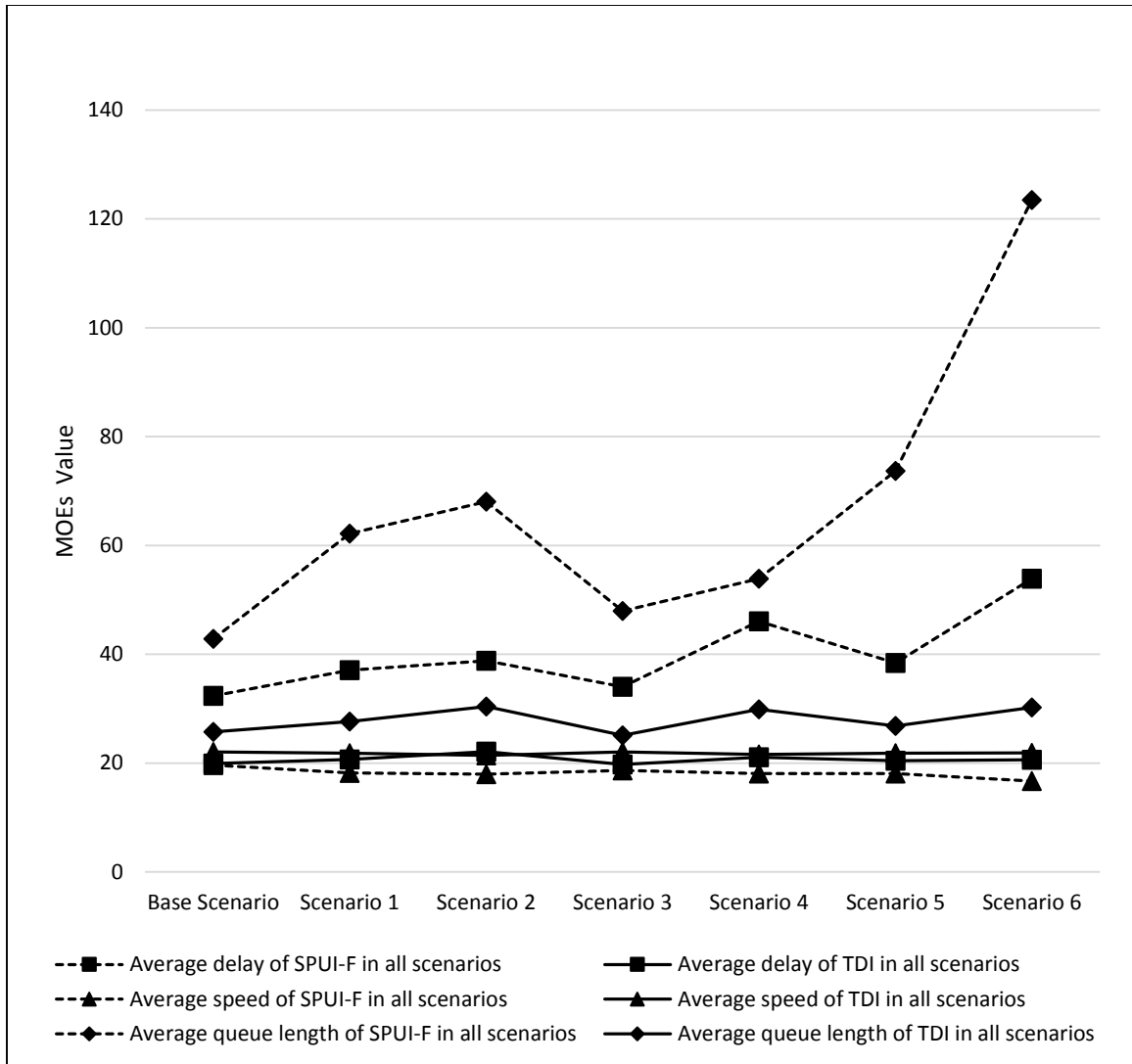


Figure 38. MOEs Results Summary

Future works can be focused on the influence towards the SPUI-F and TDI. Hardware in the loop simulation may participate in the research to make the research more realistic. On the other hand, the signal coordination of the plumb lane could be enhanced after this research, new signal coordination plans could be developed and implemented.

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