RESEARCH & DEVELOPMENT

Operational Applications of Signalized Offset T-Intersections - Final Report

Institute for Transportation Research and Education (ITRE)
North Carolina State University

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16. Abstract

NCDOT maintains a significant number of T intersections with developable land occupying the vacant fourth leg. When a need for a fourth leg is established, NCDOT must determine the optimal location of the leg. Common options include adding the leg to the existing intersection as well as moving the leg up or downstream of the existing intersection to create an offset-T configuration.

This report first documented the established literature and knowledge regarding the operational and safety impacts of the offset T-intersection versus the 4-leg intersection. Then, it presented results from a microsimulation-based operational study over five development scenarios, two demand to capacity ratios, and nine intersection geometric designs, which resulted in 90 combinations of simulation scenarios. Queue length and delay were employed as measurements of effectiveness. Based on the simulation effort and associated measures, this research provided practice-ready guidelines to NCDOT on the selection of the optimal intersection geometry for each specific development project. In general, this research recommended the L-R offset T-intersection for new developments given its significant benefits in terms of reducing delay, particularly delay to the major street movements.

17. Key Words **Offset T-Intersection, Signal Scheme, Traffic Operation, Optimal Spacing, Microsimulation**	18. Distribution Statement

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Executive Summary

NCDOT maintains a significant number of T intersections with developable land occupying the vacant fourth leg. When need for a fourth leg is established, NCDOT must determine the optimal location of the leg. Common options include adding the leg to the existing intersection as well as moving the leg up or downstream of the existing intersection to create an offset T-intersection.

This report documents the comparisons of the operational impacts of offset T-intersections versus 4-leg intersections. A VISSIM microsimulation tool was adopted for assessing the performance of both vehicle and non-vehicle traffic under various traffic volume and intersection geometric features; queue length and delay were employed as measurements of effectiveness (MOEs).

This research presented five Origin-Destination (OD) pairs to simulate different real-world development scenarios, including:

- Superstore: mix of pass by and intentional trips
- Hybrid Gas Station: majority pass by trips
- Residential AM: no pass by trips
- Residential PM: no pass by trips
- Realign: a general case that realigns the distribution of traffic flow.

Based on the simulated MOEs, this research provided practice-ready guidelines to NCDOT on the selection of the optimal intersection geometry for each specific development project, described as follows:

Superstore Development Scenario

- This research effort recommends an LR offset T-intersection with a stem spacing longer than 600 ft.

Hybrid Gas Station Development Scenario

- This research effort recommends an LR offset T-intersection; when possible, a spacing that is longer than 300 ft. is recommended.

Residential Area Development Scenario

- This research effort recommends that a LR offset T-intersection employed with a medium spacing (e.g., around 600 ft.) under a low-to-medium v/c ratio condition. However, when the v/c ratio is high, an LR offset T-intersection with a longer spacing (e.g., longer than 600 ft.) is recommended.

Realign Scenario

- This research effort recommends an LR offset T-intersection with a relatively longer spacing (i.e., longer than 900 ft.) for the Realign scenario, particularly when v/c ratio is larger than 0.7.

Although the LR offset T-intersection appears to provide the most optimal solution for the development scenarios tested, this research did not consider a RL geometry with left turn lanes which each extended the full distance between the stems, instead focusing on a geometry in which the combined length of the left turn lanes was equal to the distance between the stems. On one hand, this allowed equivalent use of right-of-way to be considered in both RL and LR scenarios; however, it should be noted that, should

additional right-of-way be available, extended left turn lanes may improve queue storage concerns making the RL offset T a viable intersection configuration under many scenarios. Besides, the research found that pedestrian and bicycle delay depend on signal phasing scheme with pedestrian delay increase with the increase of cycle length.

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1. Introduction

1.1 Background

The NCDOT Traffic Management Unit (TMU) receives requests from local governments and developers to add fourth legs at existing signalized T intersections. Requests for additional legs can occur along arterials within suburban areas, in the downtown of rural towns, or at commercial centers along highways. The TMU has been reluctant to approve such requests, believing that creating a signalized offset-T may prove more successful both from a safety and operational standpoint.

An offset T-intersection (also known as staggered intersection) is an at-grade road intersection where a conventional four-leg intersection is split into two three-leg T intersections to reduce the number of conflicts and improve traffic flow *(Rodegerdts et al., 2004; Hughes et al., 2010)*. With a 4-leg intersection, traffic on any approach would negotiate both opposing and cross traffic; however, in comparison, with a T intersection, the opposing approach is eliminated on the minor approach. Therefore, having two separate T intersections means traffic on a minor approach only has to encounter potential traffic conflicts from the major crossing approaches.

Offset T-intersections exist in two forms, and the operations of minor street users (motor vehicles, pedestrians, and bicycles) are different for each form. The forms, shown in Figure 1, are referred to as “Right-Left” (“RL”) and “Left-Right” (“LR”) so named for the path vehicles travel from one minor road to the other while crossing the major road. For the remainder of this report, it is assumed the uninterrupted street is the major street while the offset street is the minor street.

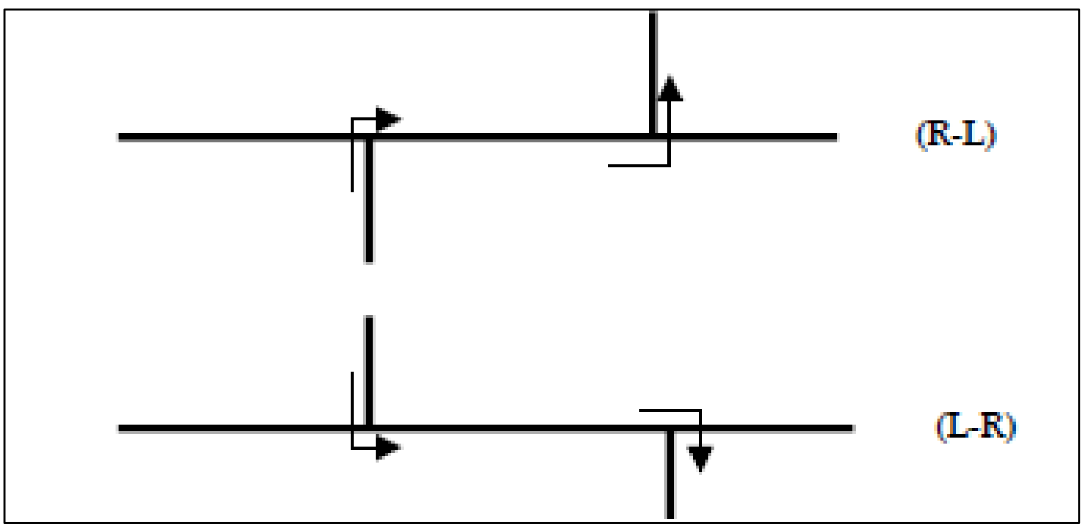


Figure 1-1. Right-Left (R-L) and Left-Right (L-R) offset designs *(Bared and Kaisar, 2001)*

Typically, offset T-intersections have stop control on the minor approaches when traffic demand is relatively low. When traffic demand is higher, signals may be installed at one or both offset T-intersections to control traffic. The key to offset T-intersections is the actual offset, or distance from one intersection to another; a shorter distance increases the likelihood of both intersections behaving as one. In addition, depending on the proximity of each T intersection, the signals may be optimized differently to provide the best progression from intersection to intersection.

1.2 Objectives and Scope

The objective of this research is to provide NCDOT with objective, scientific guidance on how offset T-intersections compare operationally to four-leg intersections for vehicles, pedestrians, and bicyclists. In particular, this project will inform NCDOT of the volume, origin-destination (OD), spacing, and signal timing variations for which the LR or RL offset T-intersection provides less delay than four-leg intersections.

2. State-of-the-Practice

2.1 Effects on Operation and Safety

In comparison with a standard 4-leg two-lane intersection, an offset T-intersection reduces the number of conflicts points from 32 to 18, indicating that an offset T-intersection has the potential to reduce the risk of collisions and improve the operational efficiency. To date, there have been a number of studies that have investigated the effects of offset T-intersection on traffic operation and safety.

In the 1980s, Mahalel et al. *(1986)* evaluated the safety and operational benefits of two types of unsignalized staggered intersections. The authors concluded that the LR design had greater reductions in injury crashes than the RL designs – primarily due to the reduced number of conflict points and speed of minor road traffic. However, no comparison was made with the 4-way standard intersection. In comparison, the RL designs had higher capacity and less delay due to the availability of lower critical gaps. Nevertheless, this research also pointed out that a staggered intersection, either LR or RL design, does cause additional traffic interference to the major road traffic, and the amount of interferences increases with the distance between the two T intersections.

Kulmula *(1997)* compared the safety performance of 4-way standard intersections and offset T-intersections in Finland. It was found that the crash rates were 1.3-1.4 times higher at 4-way intersections than offset T-intersections. Later, Monsere *(2001)* conducted a worldwide review on the safety performance of rural offset T-intersections. In general, this research indicated that crash rates at T intersections are usually lower than those of 4-way cross intersections but are dependent on volumes and other factors. Similarly, Bared and Kaisar *(2001)* synthesized the advantages of offset T-intersections and concluded that converting a standard rural 2-lane TWSC intersection to an offset T-intersection is expected to bring 20 to 30 percent reductions in total crashes and 40 percent reductions in fatal/injury crashes. Ceder and Eldar *(2002)* developed an analytical model to investigate the safety effects of staggered intersections. Results showed that converting a standard intersection to a staggered intersection could decrease the number of crashes by up to 50%, and the number of crashes decreases with the increase of stagger distance. Elvik et al. *(2009)* summarized the effects of various roadway safety measures. It was found that four-leg intersections have twice the crash rate of three-leg intersections. For signalized intersections, the injury crash rate at a T intersection was between 33% and 66% lower than a standard four-leg intersection. A second meta-analysis was conducted to determine the impact of converting to a staggered T intersection on the number of crashes. One study which contributed to the meta-analysis suggested that the LR stagger reduced overall crashes by 4% while the RL increased crashes by 7%. Nevertheless, it is necessary to point out that this result was not statistically significant.

Recently, Barua et al. *(2010)* studied rural undivided highways in Alberta, Canada and found given a crash occurred, the risk of fatality increased when the crash occurred at an offset intersection (without regard to signalization) and that signalizing the intersection reduced the risk of fatality. Chia et al. *(2013)* developed a safe system assessment framework to assess the safety effectiveness of staggered T intersections in terms of the degree of alignment with the objective of zero death and serious injuries. Generally speaking, it was found that a staggered T intersection meets a low to moderate level of alignment with the safety objective. Ma et al. *(2014)* employed a microsimulation modeling approach to investigate the efficiency and safety of the staggered intersection with a two-way left-turn lane. Simulation results showed that the average delay decreases nonlinearly with an increase in the stagger distance. On the other hand, however, this research found that staggered intersections have a significantly higher number of traffic conflicts than standard intersections, especially when the left-turn ratio is high.

For traffic operation performance, Bared and Kaisar *(2001)* found that in urban areas, for a typical intersection with a combined ADT over 14,000 vehicles and a directional split of 0.6, converting a 2-lane signalized intersection to a LR offset T-intersection is expected to decrease travel time by 5 to 20 seconds per vehicle compared to a four-leg intersection. Cai et al. *(2016)* pointed out that at a signalized staggered intersection, a long lost time is expected for the minor road through traffic to make sure that traffic spillbacks are handled appropriately. With this concern, this research effort developed a signal phasing scheme for the left-right type staggered intersection based on a sorting strategy using an early release from the upstream intersection of the coordinated pair on the through movement. Through microsimulation modeling, this research found that in comparison with the conventional staggered intersection signal control method, the proposed signal phasing reduced average delay and the maximum queue length by up to 29.7% and 26.9%, respectively.

2.2 Existing Design Guidelines

In terms of the design of offset T-intersections, Stark *(1994)* suggested intersections with offsets around 36 meters had lower crash rates than standard four-leg intersections or intersections of greater offsets; however, intersections with small offsets were more hazardous than four-leg intersections. Bared and Kaisar *(2001)* summarized a couple of general traffic flow warrants for the conversion of standard intersections to offset T-intersections. The authors pointed out that when traffic flow is greater than 10,000 ADT with 10-percent traffic on the minor road, the offset T-intersection may not be cost-effective. Ceder and Eldar *(2002)* developed an analytical model to determine the optimal stagger distance between the two adjacent unsignalized T intersections. This research first pointed out that the RL design outperforms LR design; and further suggested that the optimal stagger distance should be determined based on blocking queues, passing probabilities, budget limitations, and safety thresholds. In general, a longer stagger distance is expected to shorten the total delay.

The Delaware Department of Transportation *(DelDOT, 2009*) determined the ideal distance between intersections should be at least 350 feet. If two intersections are less than 350 feet, certain restrictions should be applied, such as implementing turn restrictions on certain movements and/or prohibiting pedestrian crossings at certain locations in and around the intersection.

Chia et al. *(2013)* investigated the operational and design factors that need to be considered when planning and designing rural offset T-intersections, which mainly included major road traffic volume, intersection capacity, stagger type and distance, land availability, and costs. The authors recommended a rural offset T-intersection should meet the following requirements: low major-road traffic volume, minor-road approach and vegetation do not obstruct sight distance, a LR stagger type with a stagger distance greater than 15 m, and have advance warning signs on the major road.

Ma et al. *(2014)* investigated the impacts of traffic volume, ratio of left turn vehicles, and stagger distance on the performance of staggered intersections. The objective was to provide transportation engineers and planners with recommendations on the implementation for staggered intersections and the appropriate stagger distances that should be considered. Through microsimulation, this research found that staggered intersections with a stagger distance shorter than 200 m showed few advantages in terms of average delay over a cross intersection. In addition, this research recommended that when determining the acceptable stagger distance range, it is necessary to take into account the actual traffic volume and left-turn ratio as well as safety concerns that could arise based on geometry and traffic volumes.

2.3 Summary

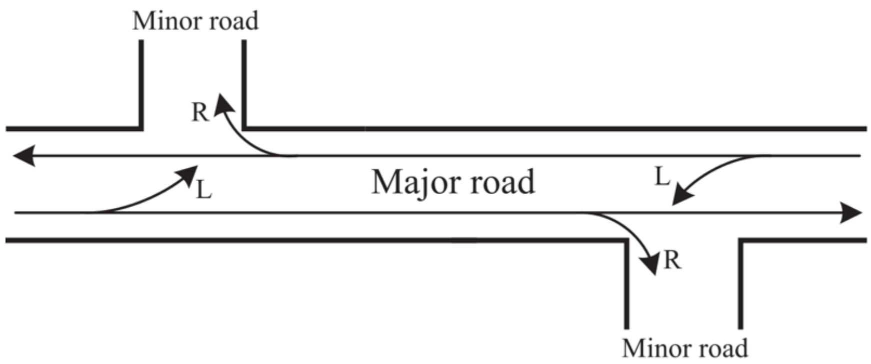
This literature review summarized that in current practice there have been a number of studies which compared the safety performance between offset-T and four-leg intersections; however, very little literature exist regarding operational comparisons. The literature which did exist mostly provided conjectures as opposed to experiment-based conclusions. Further, there are open questions regarding the optimal signal timing strategies for the offset T-intersection including if one or two controllers should be used, and if the former, how the signal phasing should be designed. More informed signalization strategies could greatly enhance the operational findings noted in this literature. In addition, none of the existing literature revealed the impacts of pedestrian and bicycle operations at offset T-intersections.

3. Experiment Design

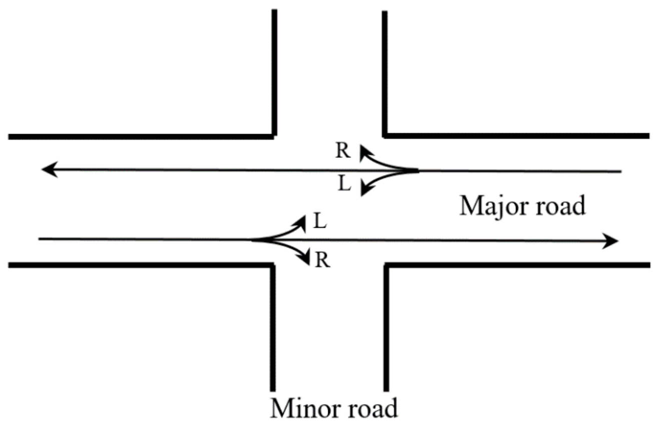
3.1 Intersection Configurations

3.1.1 Intersection Layout

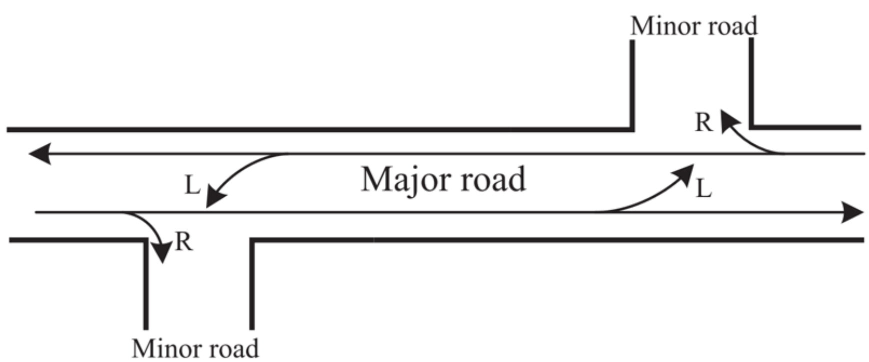
As mentioned in the "Background" section, an offset T-intersection may be in an LR form or a RL form. In addition, since the purpose of this research is to assist NCDOT with determining the optimal location of the fourth leg to be added to an existing T intersection, this research also considered the traditional standard (4-leg) intersection form. The geometrical layouts of the three intersection forms are illustrated in Figure 3-1.



(a) LR Form Offset T-Intersection



(b) 4-leg Standard Intersection



(c) RL Form Offset T-Intersection

Figure 3-1. Geometrical Layouts of Three Intersection Forms

3.1.2 Spacing Considerations

An offset T-intersection would result in a higher volume of turning traffic at all minor street approaches, which tends to call for longer turn bays (right-turn and/or left-turn). In addition, when a major street has two or more lanes, minor street through vehicles may need to make one or more lane-changing maneuver(s) which could increase the requirement of spacing length. With these considerations, the research team tested four spacing levels between the two legs (i.e., ranging from 300 ft to 1200 ft with an increment of 300 ft). In this report, any reference to a negative spacing implies an LR layout while a positive spacing implies an RL layout. For the traditional standard intersection form, this research assumed the spacing between two legs is 0 ft. A graphical illustration of the spacings is presented in Figure 3-2 below.

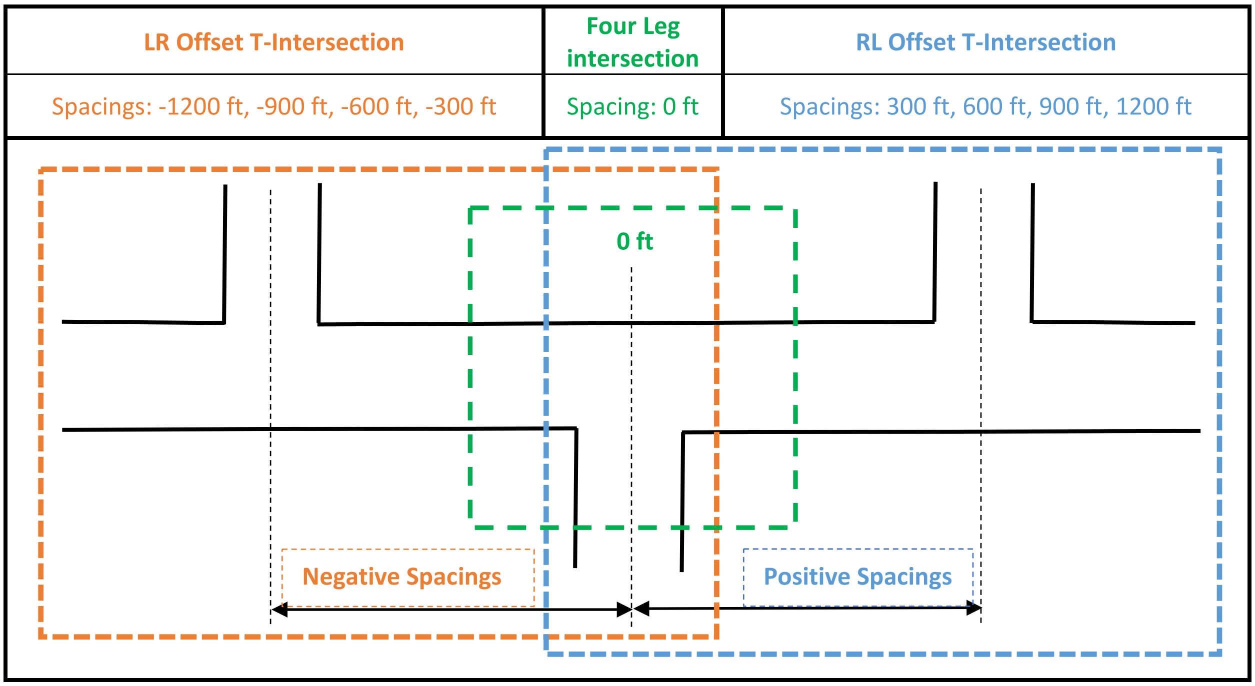


Figure 3-2. Illustration of Negative and Positive Spacings

In terms of the length of lanes, the research team assumed an exclusive left turning lane is provided on the mainline for the RL design with sufficient length to prevent turning vehicles from blocking through traffic. For the RL and LR offset T-intersections, this research maintained a right-of-way no wider than five total lanes. Therefore, for the RL offset, left turn lanes did not overlap (i.e. a two-way left turn lane) between the intersections but were placed back-to-back. This also provides the safest use of the median based on prior research (*Phillips et al., 2004*). The allocation of space for the length of exclusive left-turn lanes on the major street for the RL scenario is as follows:

- + 300 ft and + 600 ft spacing levels: the lengths of left-turn pocket are distributed proportionally based on the left turn volumes of eastbound and westbound with the following constraints:
  - The distributed pocket length must be at least 1/3 of total spacing
- + 900 ft and + 1200 ft spacing levels: the lengths of left-turn pocket are evenly distributed (50:50)

For the LR scenarios, the left turn pockets are a constant 500 feet as there is not a shared area between the two minor streets like the RL scenario. An overview of the length of exclusive lanes is presented in Table 3-1 below.

Table 3-1. Length of Lanes

Type	LR Offset (Negative Spacing)		4 - Leg		RL Offset (Positive Spacing)	
	Left Lane	Right Lane	Left Lane	Right Lane	Left Lane	Right Lane
Major Street	500 ft	200 ft	500 ft	Shared	Depends	200 ft
Minor Street	750 ft	Full Length	720 ft	720 ft / Full length	750 ft	Full Length

If sufficient right-of-way exists, the left turn lanes for the RL design may overlap resulting in more queue storage space; however, for this research effort we do not consider that design as the right-of-way availability was assumed to be constrained equally.

3.1.3 Number of Lanes

This research assumed a common rule of thumb that an exclusive left-turn lane should accommodate up to 300 vehicles per hour. Based on this assumption, if approaching left-turn volume is less than 300 vehicles per hour, the number of exclusive left-turn lanes would be one lane; otherwise, the number of exclusive lanes would be set as two lanes. For the right-turn movement on the major street, this research assigned one exclusive turn lane for LR and RL case to allow the through movement on the major street to proceed undisturbed by right-turn queues. The number of exclusive lanes in this research is shown in Table 2 below. The 4-leg standard intersection has a shared through and right turn lane due to the low volume of right turns.

Table 3-2. Number of Lanes

Type	LR Offset (Negative Spacing)			4 - Leg			RL Offset (Positive Spacing)		
	Left	Through	Right	Left	Through	Right	Left	Through	Right
Major Street	1	2	1	1	2	Shared	1	2	1
Northbound Minor Street	2	n/a	2	2	Shared	2	2	n/a	2
Southbound Minor Street	1	n/a	1	1	Shared	1	1	n/a	1

3.1.4 Bicycle Lanes and Pedestrian Crosswalks

To accommodate multiple modes at offset T-intersections, this research also evaluated the performance of bicycle lanes and pedestrian crosswalks. For bicycle lanes, this research designed exclusive bicycle lanes for all approaches (including both offset T-intersections and the standard four-leg intersection); each bicycle lane is designed as one-way which aligns with the direction of vehicle travel lanes. In case an exclusive right-turn lane exists, the bicycle lane will be placed between the through lane and right turn lane. In terms of pedestrian crosswalks, for a four-leg intersection, pedestrian crosswalks are designed for all the directions; for offset T-intersections, the design of pedestrian crosswalks also accommodated in all the directions; however, pedestrian crosswalks were not modeled at locations where they conflict with the left-turn traffic from minor streets (the LR condition) and were instead only assumed on the outside of the minor in this case.

An illustration of the lane configurations for the bicycle and pedestrian paths for a LR offset configuration is presented in Figure 3-3, where the gray layers represent driving lanes, red lines represent bicycle lanes, and green lines represent pedestrian crossings. These paths are also representative of the crossing patterns used for RL offset.

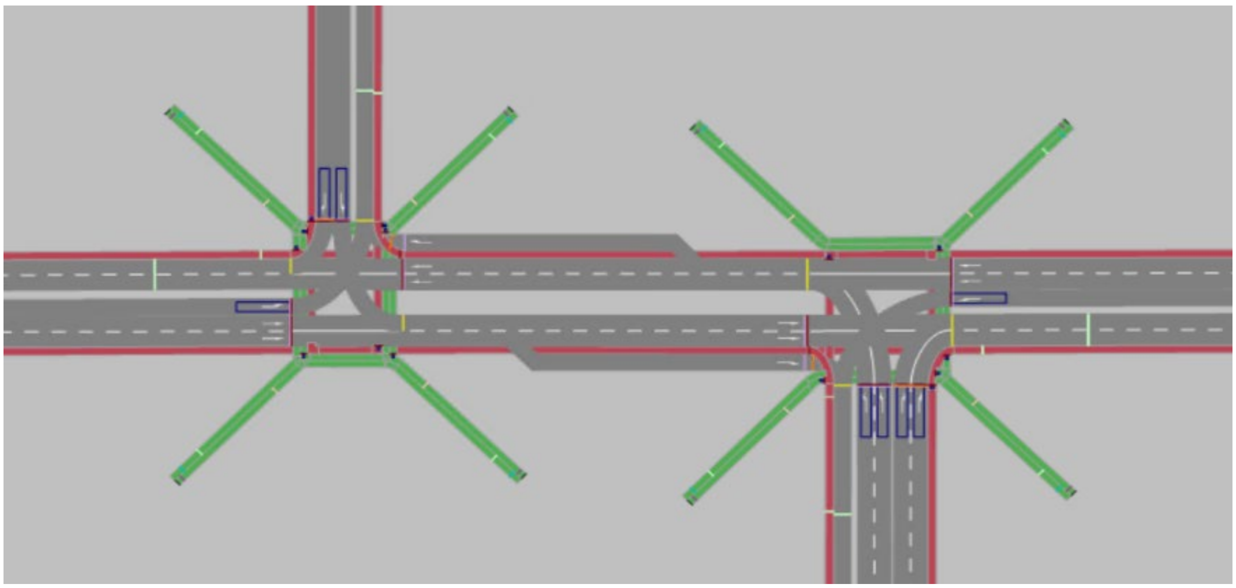


Figure 3-3. Illustration of bicycle lane and pedestrian crossings

3.2 Traffic Flow Scenario

3.2.1 Origin-Destination pairs

This research effort presented five OD pairs to simulate different real-world development scenarios for the newly developed fourth leg, listed as follows:

- Superstore: mix of pass by and intentional trips
- Hybrid Gas Station: majority pass-by trips
- Residential AM: no pass-by trips
- Residential PM: no pass-by trips
- Realign: a general case that realigns the distribution of traffic flow, allowing traffic to use the new fourth leg as a route to further downstream locations along the leg

3.2.2 Trip Generation

For the superstore, hybrid gas station and residential development scenarios, the Institute for Transportation Engineers (ITE) Trip Generation Manual *(ITE, 2017)* was used to estimate the induced traffic volume generated by the developments. The ITE vehicle trip generation rates used in this research effort for each development scenario (i.e., Superstore, Hybrid Gas Station, Residential AM, and Residential PM) are presented in Appendix A.

It is necessary to point out that for the 5th case (realign scenario), through movements on minor streets were increased in comparison with the other four cases. For the realign scenario, 25 percent of the total approach volume on minor streets was a through movement; in comparison, 80 percent of total approach volume on major streets was a through movement.

3.2.3 Volume to Capacity Level

This research considered two volume-to-capacity (v/c) ratio levels when developing models: 1) a v/c ratio of 0.9 to represent heavy traffic demand periods, such as morning and evening peak hours during workdays and 2) a v/c ratio of 0.7 was used to represent normal workday traffic demand scenarios. The v/c ratios were measured relative to a four-legged intersection.

In addition, this research effort assumed that traffic flow on the major street is not evenly distributed. During the morning peak period, it was assumed 60 percent of the total traffic travel westbound (40 percent eastbound traffic). In comparison, during the evening peak period, 60 percent of the total traffic travel was eastbound (40 percent westbound traffic). It was also assumed that volumes on the minor leg were half of the volumes on the major leg.

3.2.4 Summary of Turning Movement Volume

Finally, turning movement volumes for the three intersections for each development scenario were estimated, as documented in Table 3-3 (v/c=0.7) and Table 3-4 (v/c=0.9), respectively. These turning volume scenarios represent various movement combinations expected either: over the course of a day, for various land uses, or for various functional classifications of the intersecting roadway. Then, based on the calculated turning volume, detailed vehicle inputs for each VISSIM model were determined, as attached in Appendix B. In this report, traffic volume means the total number of vehicles entering an approach of the intersection; vehicle static route refers to the proportions of turning movement (i.e., left-turn, through, and right-turn) among the input traffic volume at this approach.

Table 3-3. Turning Movement Volume for Three Intersection Layouts (v/c = 0.7)

4-Leg Layout	**Turning Movement Volumes (vph)**											
	NB			**SB**			**EB**			**WB**		
	LT	**Thru**	**RT**	**LT**	**Thru**	**RT**	**LT**	**Thru**	**RT**	**LT**	**Thru**	**RT**
Hybrid Gas Station (PM)	213	29	320	179	30	120	178	789	169	113	526	119
Superstore (PM)	146	101	219	268	104	179	264	542	116	77	361	176
Residential AM	394	19	263	45	56	68	15	649	139	208	973	22
Residential PM	237	63	355	44	37	30	76	877	188	125	585	50
Realign	165	138	248	165	92	110	110	881	110	73	588	73
LR Layout	**Left Intersection**						**Right Intersection**					
	SB		**EB**		**WB**		**NB**		**EB**		**WB**	
	LT	**RT**	**LT**	**Thru**	**Thru**	**RT**	**LT**	**RT**	**Thru**	**RT**	**LT**	**Thru**
Hybrid Gas Station (PM)	209	120	178	959	739	148	242	320	969	199	113	645
Superstore (PM)	372	179	264	658	507	277	247	219	809	220	77	537
Residential AM	101	68	15	788	1367	41	412	263	694	195	208	995
Residential PM	81	30	76	1065	821	113	300	355	921	225	125	635
Realign	257	110	110	991	753	211	303	248	1047	202	73	661
# of lanes	1	1	1	2	2	1	2	2	2	1	1	2
RL Layout	**Left Intersection**						**Right Intersection**					
	NB		**EB**		**WB**		**SB**		**EB**		**WB**	
	LT	**RT**	**RT**	**Thru**	**Thru**	**LT**	**LT**	**RT**	**Thru**	**LT**	**RT**	**Thru**
Hybrid Gas Station (PM)	213	349	968	169	143	646	179	150	207	1109	639	119
Superstore (PM)	146	320	805	116	181	540	268	283	365	761	438	176
Residential AM	394	281	664	139	265	1041	45	124	34	911	1181	22
Residential PM	237	418	952	188	162	614	44	67	139	1232	710	50
Realign	165	386	991	110	165	698	165	202	248	1129	661	73
# of lanes	2	2	1	2	2	1	1	1	2	1	1	2

Table 3-4. Turning Movement Volume for Three Intersection Layouts (v/c = 0.9)

4-Leg Layout	**Turning Movement Volumes (vph)**											
	NB			**SB**			**EB**			**WB**		
	LT	**Thru**	**RT**	**LT**	**Thru**	**RT**	**LT**	**Thru**	**RT**	**LT**	**Thru**	**RT**
Hybrid Gas Station (PM)	288	29	432	179	30	120	178	1067	229	152	711	119
Superstore (PM)	250	101	376	268	104	179	264	928	199	133	619	176
Residential AM	520	19	347	45	56	68	15	857	184	275	1285	22
Residential PM	311	63	467	44	37	30	76	1154	247	165	769	50
Realign	212	177	319	212	118	142	142	1133	142	94	755	94
LR Layout	**Left Intersection**						**Right Intersection**					
	SB		**EB**		**WB**		**NB**		**EB**		**WB**	
	LT	**RT**	**LT**	**Thru**	**Thru**	**RT**	**LT**	**RT**	**Thru**	**RT**	**LT**	**Thru**
Hybrid Gas Station (PM)	209	120	178	1295	999	148	317	432	1246	259	152	830
Superstore (PM)	372	179	264	1127	869	277	351	376	1196	303	133	794
Residential AM	101	68	15	1041	1806	41	539	347	902	240	275	1308
Residential PM	81	30	76	1401	1081	113	374	467	1198	284	165	820
Realign	330	142	142	1275	968	271	390	319	1346	260	94	850
# of lanes	1	1	1	2	2	1	2	2	2	1	1	2
RL Layout	**Left Intersection**						**Right Intersection**					
	NB		**EB**		**WB**		**SB**		**EB**		**WB**	
	LT	**RT**	**RT**	**Thru**	**Thru**	**LT**	**LT**	**RT**	**Thru**	**LT**	**RT**	**Thru**
Hybrid Gas Station (PM)	288	461	1245	229	182	831	179	150	207	1498	863	119
Superstore (PM)	250	476	1192	199	237	797	268	283	365	1303	751	176
Residential AM	520	366	872	184	332	1353	45	124	34	1204	1561	22
Residential PM	311	530	1230	247	202	799	44	67	139	1621	934	50
Realign	212	496	1275	142	212	897	212	260	319	1452	850	94
# of lanes	2	2	1	2	2	1	1	1	2	1	1	2

3.3 Signal Phasing Scheme

For the 4-leg intersection, the signal timing process followed the standard signal optimization procedure, where a four-critical (4C) phase signal timing plan was applied, and the Highway Capacity Manual (HCM) method was employed for determining the optimal cycle length. PTV VISTRO's v/c balancing algorithm was used to determine the green spits *(PTV Group, 2020)*. Therefore, this section mainly presents the signal phasing schemes for offset T-intersections along with the design of bicycle and pedestrian signals. It was assumed all left turns were protected. Both LR and RL offsets were analyzed with a three critical-phase signal timing plan with coordination of the major through movements. In all cases, this research adopted the PTV VISTRO software package to identify the optimal signal timing schemes for each O/D scenario under a given v/c ratio *(PTV Group, 2020)*. The primary reason for choosing VISTRO for generating the optimal signal timing schemes is the flexibility of the controller for custom signal timing schemes as well as the compatibility with the microscopic simulation software used. Cycle lengths of 80 to 130 seconds at intervals of 10 seconds were analyzed. The signal timing parameters for each scenario to be tested in VISSIM microsimulation are attached in Appendix C.

3.3.1 LR Offset Layout

For a LR offset intersection, the research team proposed three phasing schemes to accommodate different spacing levels: split phasing, three-critical phase lead (3CLead) and three-critical phase lag (3CLag), respectively. A graphical illustration of the movements at an LR offset T-intersection is presented in Figure 3-4, where phases 22 and 26 refer to the major street through movements within the stem.

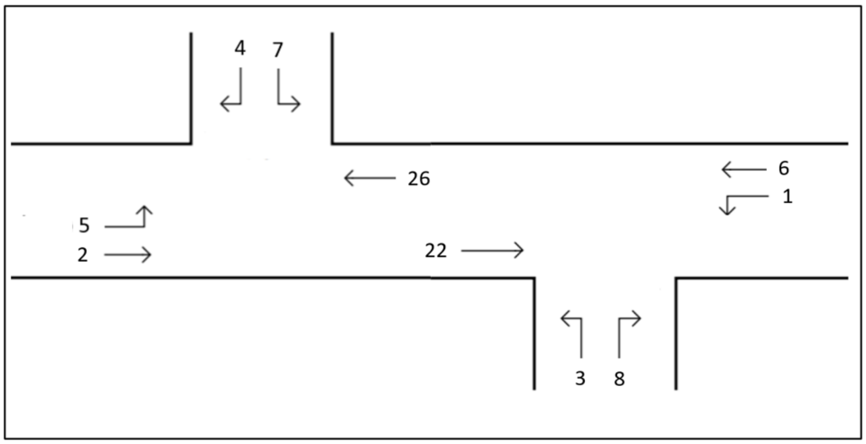


Figure 3-4. Illustration of Movements at LR Offset T-Intersection

In practice, a LR split phasing scheme should utilize lead-lag left-turn phasing for the major street with split phasing for the minor street as this promotes progression when undersaturated (v/c < 1) conditions are present. The phasing diagram for the split phasing scheme is illustrated in Figure 3-5. LR split phasing usually aims at accommodating progression of the westbound through movement (WBT); ideally, the green time of phase 5 (eastbound left-turn movement, EBL) should be less than the travel time of WBT between two intersections. Thus, it is more suitable for scenarios with a heavy WBT demand and a long stem spacing. In this research, the LR split phasing was applied in the following two scenarios: Residential AM with stem lengths of 900 and 1200 feet.

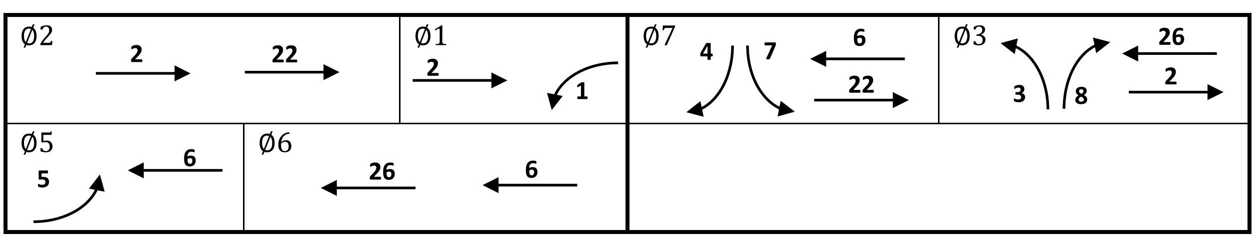


Figure 3-5. Phasing diagram of LR split phasing scheme. *Note: Movements between the stems (22 and 26) are shown for the east and west intersections for reference with Figure 3-4.*

The 3-critical phase left-turn lead phasing scheme (3CLead) utilized at the LR offset T-intersection is depicted in Figure 3-6. This phasing scheme required that the green time of the two major streets left-turn movements (i.e., Phase 1 WBL, and Phase 5 EBL) be less than the travel time of the major street through movements between the two intersections. Thus, it is more suitable for scenarios with a relatively long stem spacing. In this research, the 3CLead phasing was applied at the following eight scenarios: Superstore, Hybrid Gas Station, Residential PM and Realign with stem lengths of -1200 and -900 feet.

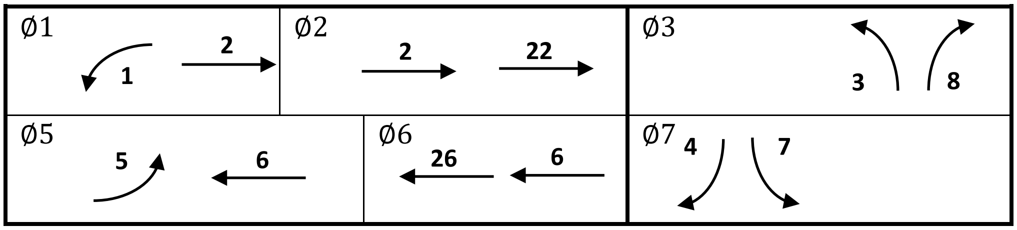


Figure 3-6. Phasing diagram of 3CLead phasing scheme. *Note: Movements between the stems (22 and 26) are shown for the east and west intersections for reference with Figure 3-4.*

The 3-critical phase LR offset T-intersection left-turn lag phasing scheme (3CLag) is depicted in Figure 3-7. This phasing scheme requires that the green time of the two major street through movements (i.e., Phase 22 EBT, and Phase 26 WBT) to be larger than the travel time of the major street through movements between the two intersections. Thus, it is more suitable for scenarios with a shorter stem spacing. In this research, the 3CLag phasing was applied at the following ten scenarios: Superstore, Hybrid Gas Station, Residential AM, Residential PM and Realign with stem lengths of -600 and -300 feet.

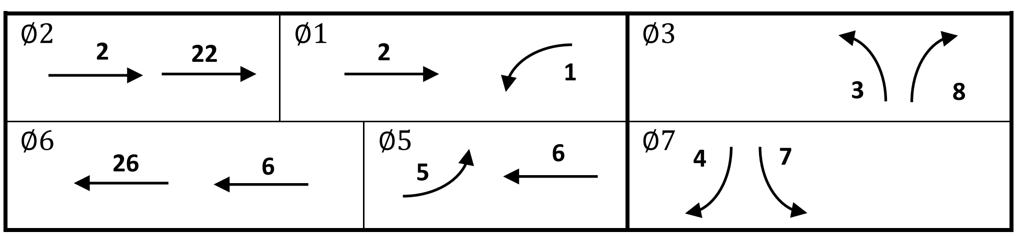


Figure 3-7. Phasing diagram of 3CLag phasing scheme. *Note: Movements between the stems (22 and 26) are shown for the east and west intersections for reference with Figure 3-4.*

3.3.2 RL Offset Layout

A graphical illustration of the movements at a RL offset T-intersection are presented in Figure 3-8. Like the LR offset layout, phases 22 and 26 refer to the major street through movements within the stem. Then, this research proposed two phasing schemes to accommodate different spacing levels.

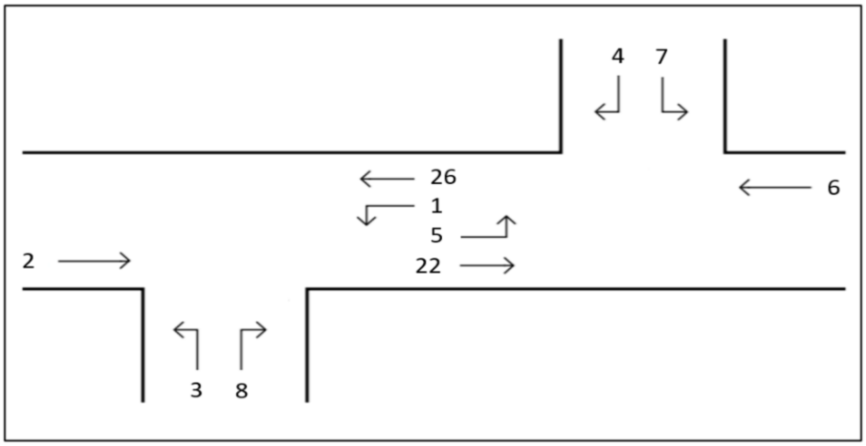


Figure 3-8. Illustration of Movements at RL Offset T-Intersection

Signal timing options for the RL offset intersection include the modification of the Texas 3-Phase (T3Lag) scheme. This option, shown in Figure 3-9 under a one controller scenario, has three critical phases. In Figure 3-8, the mainline left turns are lagged, which allows for the initial queue of minor right turns to proceed under a protected phase (Phases 2 and 5). This reduces potential conflicts of minor right-turning vehicles with pedestrians. This phasing scheme should better accommodate the progression of EBT and WBT movements, particularly when the stem spacing is short. For the RL scenario, this phasing scheme applied to the following ten scenarios: Superstore, Hybrid Gas Station, Residential AM, Residential PM, and Realign with stem lengths of 300 and 600 feet.

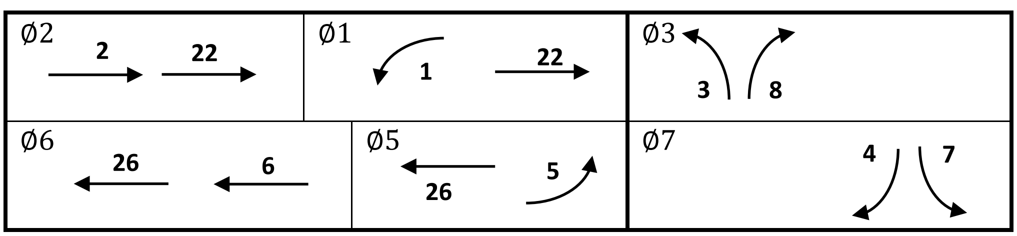


Figure 3-9. Phasing diagram of T3Lag phasing scheme. *Note: Movements between the stems (22 and 26) are shown for the east and west intersections for reference with Figure 3-8.*

As the offset spacing increases, the likelihood of a minor vehicle being able to turn right onto the major street and then left onto the minor street in one phase decreases. However, the increased offset does allow for increased storage of vehicles. Therefore, for longer stem lengths with the RL offset, the 4-critical phase split phasing (4CSplit) scheme was employed, as illustrated in Figure 3-10. The 4CSplit phasing should accommodate the progression of westbound movements, particularly for long stem spacing scenarios. In this research, the 4CSplit phasing was applied in the following ten scenarios: Superstore, Hybrid Gas Station, Residential AM, Residential PM, and Realign with stem lengths of 900 and 1200 feet.

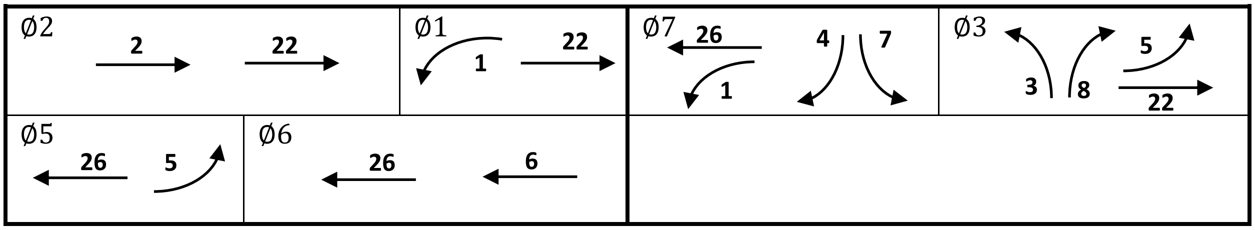


Figure 3-10. Phasing diagram of 4CSplit phasing scheme. *Note: Movements between the stems (22 and 26) are shown for the east and west intersections for reference with Figure 3-8.*

3.4 Performance Measures

Since the primary focus of this research is traffic operations, two typical measures of effectiveness (queue length and delay) were selected to assess the performance of each scenario and phasing scheme. These are defined in the following sections.

Queue Length:

Queue length analysis was conducted for vehicular traffic only. This performance measure aims to investigate the risk of queue spillback of through vehicles from the downstream intersection into the upstream intersection, as well as left-turn movement spillback into through movement lanes under different spacing scenarios.

The impacts of spacing on through movement queue spillback can be estimated as:

- Through movement queue/ Intersection spacing = $\frac{q_{Through}}{Spacing_{TH}}$

The impacts of spacing on left-turn traffic spilling back into the through lane(s) can be estimated as:

- Left-turn max queue / LT lane storage = $\frac{Max\ q_{LT}}{Storage_{LT}}$

Delay:

Delay analysis was conducted for all traffic modes (i.e., vehicles, bicycles, and pedestrians). The simulated delays were evaluated by route. The routes were classified into four categories based on the origin and destination (i.e., Main to Main, Minor to Minor, Main to Minor, and Minor to Main, respectively). Turning movements contained by each category are listed as follows:

- Main Street to Main Street: EBT & WBT
- Minor Street to Minor Street: NBT & SBT
- Main Street to Minor Street: EBL, EBR, WBL & WBR
- Minor Street to Main Street: NBL, NHBR, SBL & SBR

In addition, pedestrian delays were calculated based on the average of the following three crossing maneuvers:

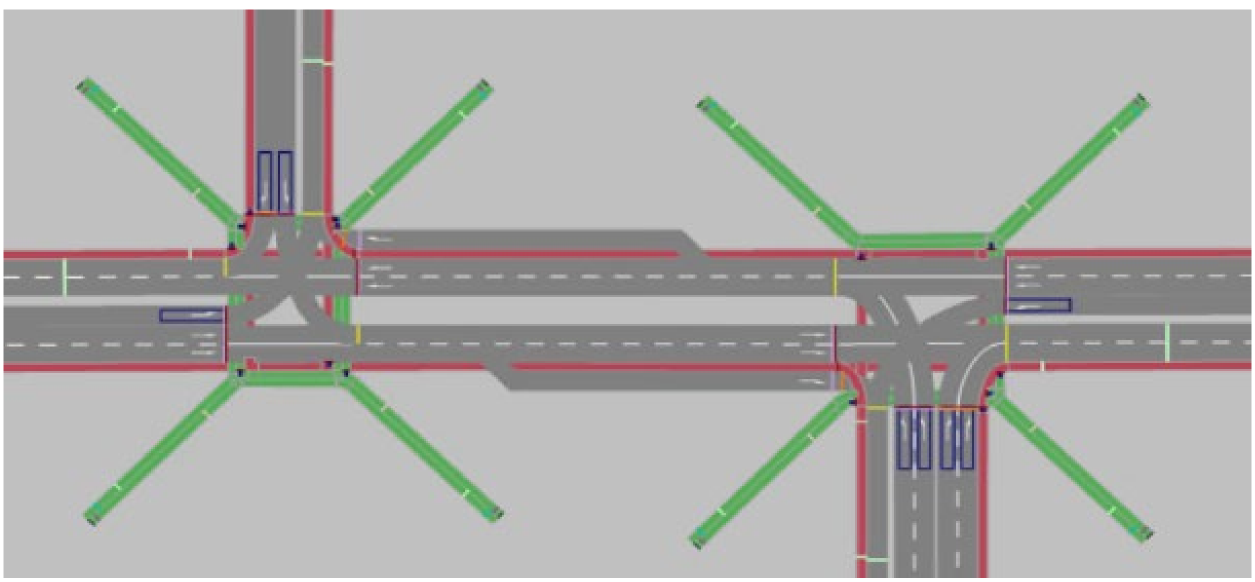
- Ped main street crossing

- Ped minor street crossing
- Ped diagonal crossing (i.e., main/minor street crossing then minor/main street crossing)

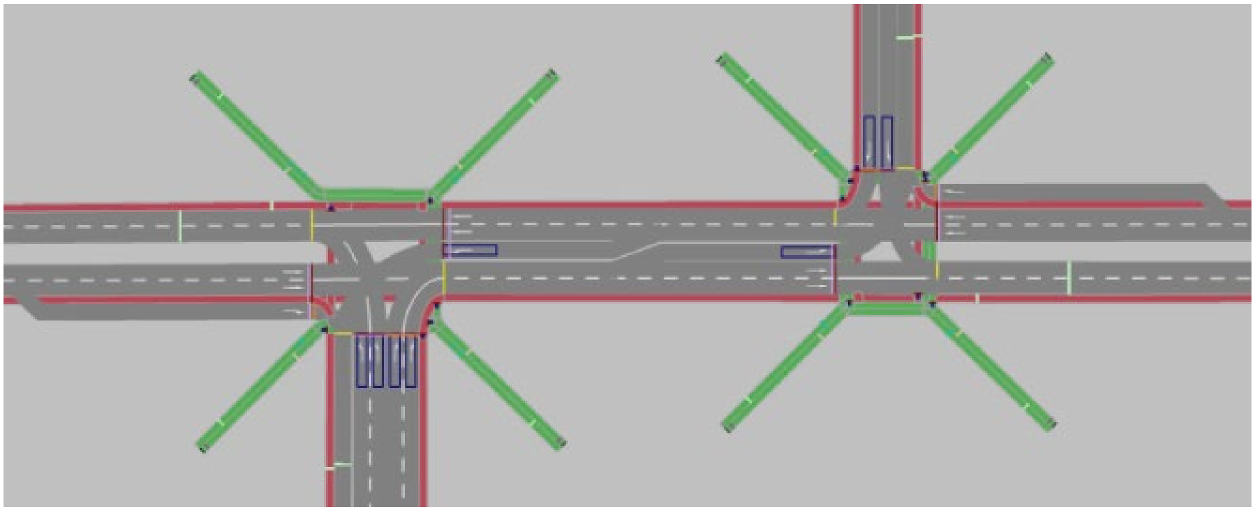
It is necessary to point out that for pedestrian traffic, this research only considered pedestrian control delay at each intersection; delay due to the increased travel distance between two intersections was not considered

4. Development of Simulation Models

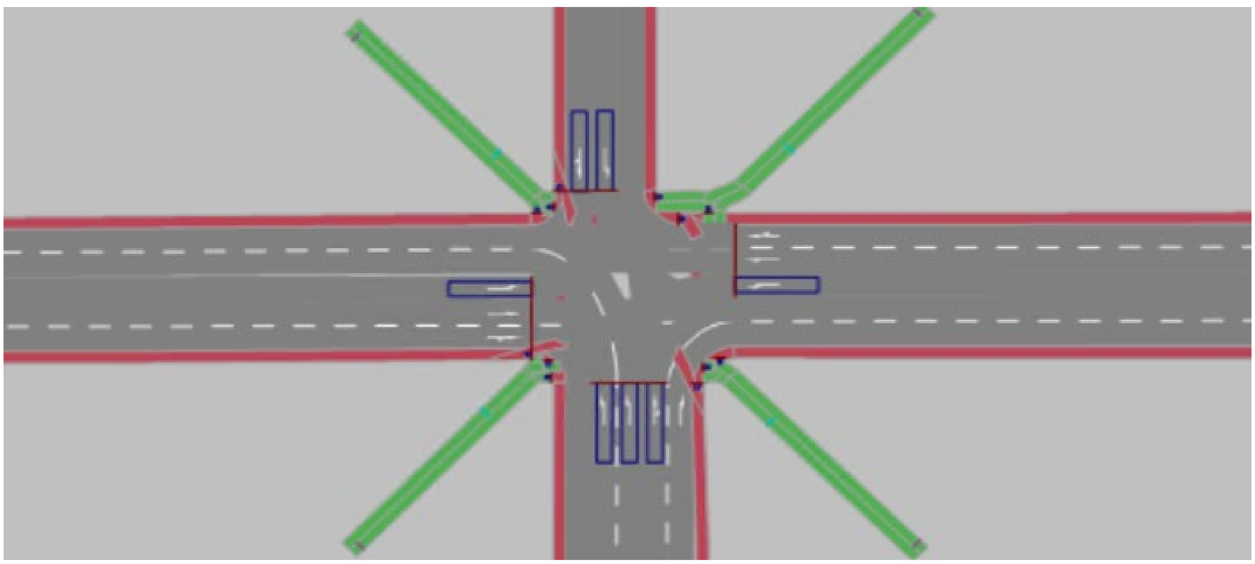
Based on the pre-determined intersection configurations, the microscopic simulation models were developed using the PTV VISSIM software package. A total of 90 simulation scenarios were designed to test the performance of offset T-intersections under various demand levels (i.e., 0.7 and 0.9), O/D patterns (i.e., Residential AM, Residential PM, Hybrid Gas Station, Superstore, and Realign), and spacing levels (i.e., -1200 ft to 1200 ft). A detailed description of the 90 simulation scenarios is attached in Appendix D. An example of the developed LR offset T-intersection, 4-leg standard intersection, and RL offset T-intersection VISSIM models are illustrated in Figure 4-1 a-c. Grey links are vehicle lanes, red links are bicycle lanes, and green links are pedestrian sidewalks. Simulation time was set as 3900 seconds where the first 300 seconds was for system warm-up to allow traffic to get to normal operation, and the remaining 3600 seconds was for data collection. To minimize the potential impact of the stochastic feature of traffic flow on performance measurement, for each simulation scenario this research effort conducted 30 simulation runs with different random seeds.



(a) LR Offset T-Intersection



(b) RL Offset T-Intersection



(c) 4-Leg Standard Intersection

Figure 4-1. Illustration of VISSIM Microsimulation Models

5. Simulation Results

This chapter presents graphical comparisons of the simulated queue length and delay results for the five OD patterns. For each OD pattern, this research investigated two v/c ratios and nine spacing levels, which yielded a total of 90 simulation scenarios. For each scenario (i.e., any combination of OD pattern, v/c ratio, and spacing level), a performance measurement result is the average of 30 simulation runs. It is necessary to clarify that for the queue length study, this chapter employed two alternative queue length measures for critical movements: ratio of average queue length divided by spacing (major road through movements), and ratio of the maximum queue length divided by storage (major road left-turn movements, for RL offset only). Details of the simulated queue lengths and delays for each movement are documented in Appendices E and F, respectively.

In addition to the quantitative comparisons of the simulated performance measures, this research effort also qualitatively presented the anticipated service impact for each stem spacing scenario. The anticipated impacts are described in Table 5-1:

Table 5-1. Description of Anticipated Service Impacts for each Performance Measure

Performance Measure	Description of Anticipated Service Impacts		
	High Impact	**Medium Impact**	**Low Impact**
Queue Length	Max. queue length > Storage	Max. queue length > 70% of Storage (< Storage)	Max. queue length < 70% of Storage
Delay	Avg. Delay > 80 sec	Avg. Delay > 35 sec < 80 sec	Avg. Delay < 35 sec

Note: "High Impact" refers to the Highway Capacity Manual (HCM) level-of-service (LOS) F; "Medium Impact" refers to HCM LOS D and E; "Low Impact" refers to HCM LOS A, B and C.

5.1 Superstore

5.1.1 Anticipated Service Impact

Based on the analyses of the simulated performance measures and in accordance with the detailed simulation outputs documented in the Appendices, a qualitative description of the anticipated service impact and movements that may experience significant impacts are presented in Table 5-2. This table is meant to serve as the primary reference for planning level considerations for each of the possible development types. For the Superstore development scenario, using both of the two MOEs, this research effort recommends a LR offset T-intersection with a relatively longer spacing to reduce the impact of the new development. The analysis for each MOE is described in more detail in the following subsections. In addition, this research applied the Analysis of Variance (ANOVA) statistical test on the delay measure of several key movements (i.e., major street through and left turn movements) and verified that the recommended offset T-intersection configurations outperform the regular 4-Leg intersection at 0.05 significance level, as shown in the Table E1 of Appendix E.

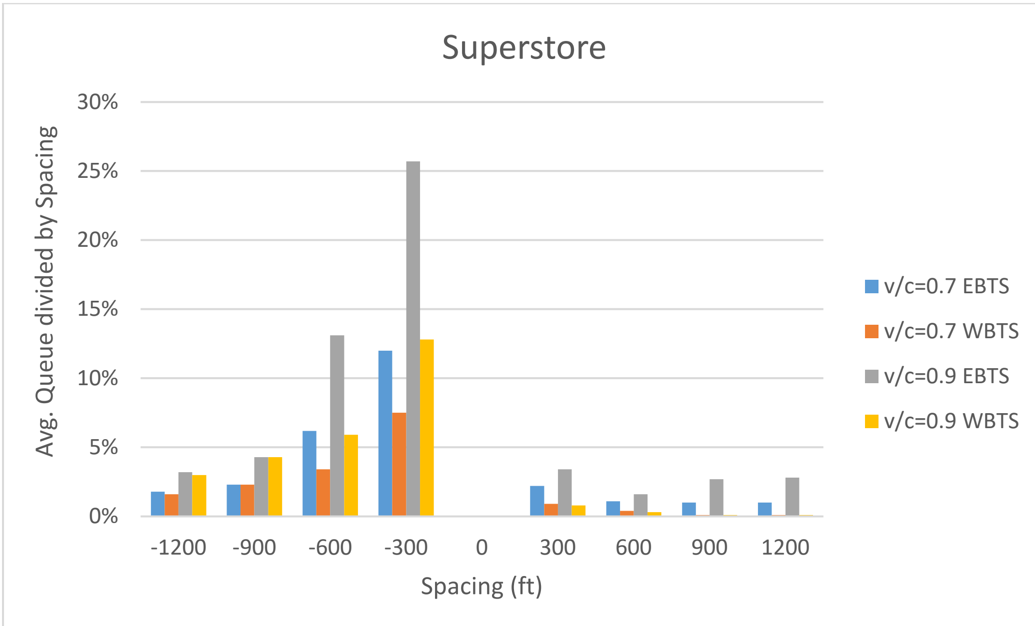
Table 5-2. Operational Performance of Various Intersection Layouts for the Superstore Development Scenario

v/c = 0.7					
Intersection Layout	**Spacing (ft)**	**Delay**		**Queue Length**	
		Anticip. Impact	**Movements that May Experience Significant Delay**	**Anticip. Impact**	**Movements that May Experience Significant Queueing**
LR Offset	**-1200**	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	SBT, EBL, NBL, SBL	Low	n/a
	-300	Medium	SBT, EBL, NBL, SBL	Low	n/a
4-Leg	**0**	High	SBL, EBL, WBL, NBL	Low	n/a
RL Offset	**+300**	Medium	NBT, SBT, EBL, WBL	High	EBL, WBL
	+600	Medium	NBT, SBT, EBL, WBL	High	EBL
	+900	High	EBL, NBT, SBT, WBL, NBL, SBL	Medium	n/a
	+1200	High	EBL, NBT, SBT, WBL, NBL, SBL	Low	n/a
v/c = 0.9					
LR Offset	**-1200**	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	EBT, NBT, SBT, EBL, NBL, SBL	Low	n/a
	-300	High	EBT, NBT, SBT, EBL, NBL, SBL	Low	n/a
4-Leg	**0**	High	EBT, WBT, EBL, WBL, NBL, SBL	Low	n/a
RL Offset	**+300**	Medium	EBT, NBT, SBT, EBL, WBL, SBL	High	EBL, WBL
	+600	Medium	NBT, SBT, EBL, WBL, SBL	High	EBL, WBL
	+900	High	EBL, EBT, NBT, SBT, WBL, NBL, SBL	Medium	EBL
	+1200	High	EBL, EBT, NBT, SBT, WBL, NBL, SBL	Low	n/a

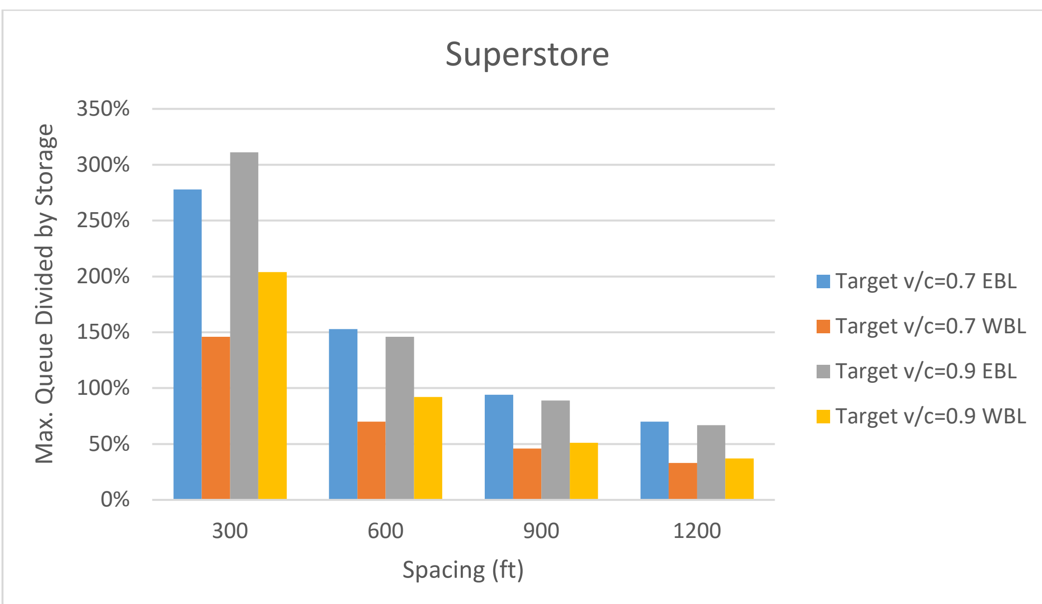
5.1.2 Queue Length

Figure 5-1 presents graphical illustrations of the average through movement queue length divided by spacing ratio and maximum left-turn queue length divided by storage. Recall the queue length divided by the spacing ratio is a measure for the through movements which queue between the stems (as opposed to those though movements with queue storage external to the stems), referenced as the eastbound through movement between the stems (EBTS) and the westbound through movement between the stems (WBTS).

From Figure 5-1(a), it was found that for both v/c levels, RL offsets (positive spacings) are generally superior to LR offsets (negative spacings) in terms of avoiding through movement queuing at signals. For LR offset T-intersections, queue length to spacing ratio decreases with the increase of spacing. When designing an RL offset T-intersection for Superstore development scenario, Figure 5-1(b) shows that an RL offset T-intersection usually requires a longer stem spacing (e.g., > 900 ft) to prevent queue spillback, even if under a relatively low v/c level.



(a) Average Through Movement Queue Length Divided by Spacing



(b) Maximum Left-Turn Movement Queue Length Divided by Storage

Figure 5-1. Queue Length under Various Spacing Levels for Superstore Development Scenario. *Note: "EBTS" and "WBTS" refer to the eastbound/westbound through traffic between the stem.*

5.1.3 Delay

Figure 5-2 compares vehicle delay under two v/c levels for four movement groups: main street to main street, minor street to minor street, main street to minor street, and minor street to main street, respectively. Major findings from Figures 5-2(a) and 5-2(b) are listed as follows; detailed delay data for the Superstore development under two v/c levels are documented in Tables F1 and F6 of Appendix F, respectively.

Main Street to Main Street

- ✓ LR offset, a longer spacing generally resulted in a lower vehicle delay for EBT movement; the spacing does not show a significant impact on WBT movement
- ✓ RL offset, a shorter spacing generally resulted in a lower delay
- ✓ Both LR and RL offset T-intersections seem superior to a 4-leg intersection under high v/c ratio conditions

Minor Street to Minor Street

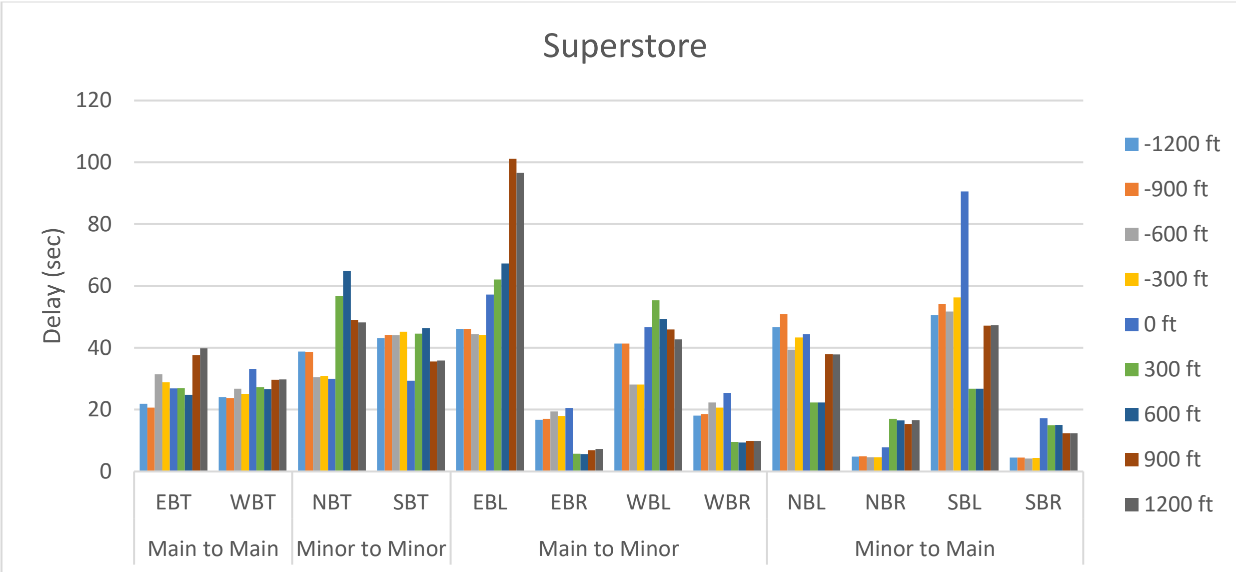
- ✓ 4-leg intersection has the lowest delay for minor street movements
- ✓ LR offset, delay tends to decrease with increased spacing
- ✓ RL offset, delay increases with increased spacing

Main Street to Minor Street

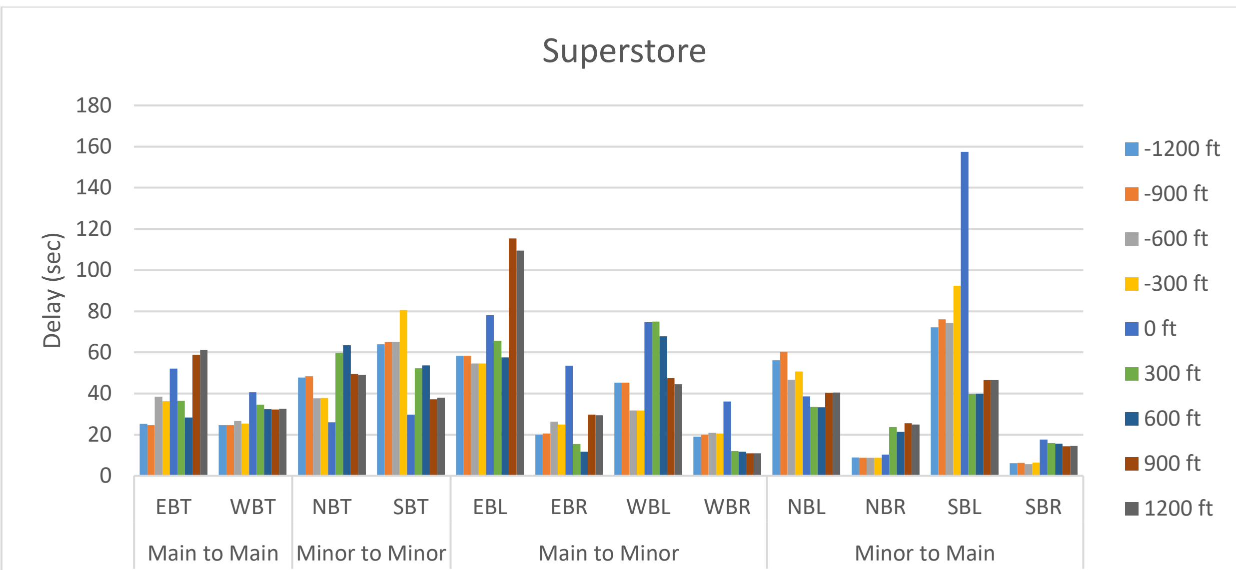
- ✓ Performance depends on movement; right turns have lower delays than left turns
- ✓ For left-turn movements, general LR offset outperforms RL offset
- ✓ RL offset is particularly beneficial to main street right-turn movements

Minor Street to Main Street

- ✓ For minor street left turn movements, generally the RL offset is superior to LR offset
- ✓ LR offset is particularly beneficial to minor street right-turn movements



(a) v/c=0.7



(b) v/c=0.9

Figure 5-2. Movement-based Vehicle Delay under Various Spacing Levels for the Superstore Development Scenario

5.2 Hybrid Gas Station

5.2.1 Anticipated Service Level

The qualitative description of the anticipated service impact and movements that may experience significant impacts for the hybrid gas station development scenario are presented in Table 5-3. This research recommends a LR offset T-intersection for the hybrid gas station development scenario; when possible, a relatively longer spacing is recommended.

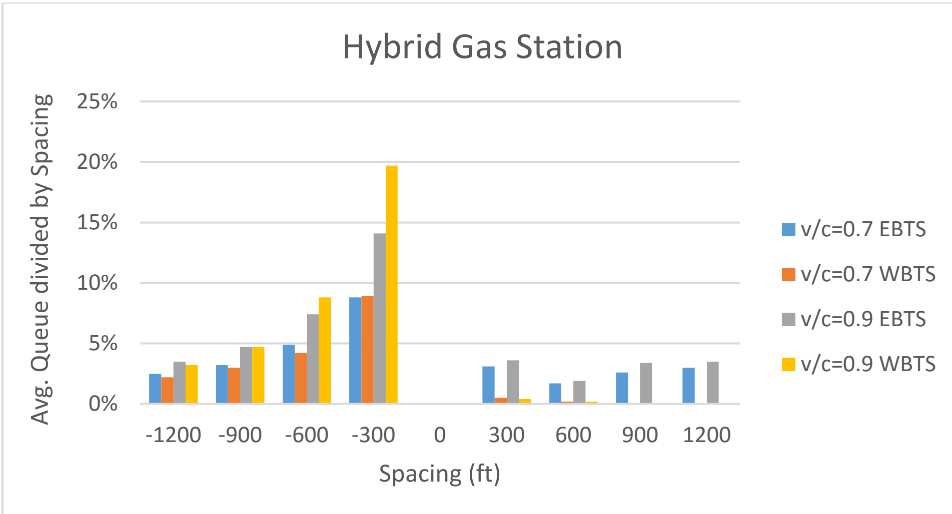
The Analysis of Variance (ANOVA) statistical test on the delay measure of major street through and left turn movements are presented in Appendix E2. It was concluded that the recommended offset T-intersection design generally outperforms the 4-leg intersection design expected for the major street left-turn movements under a lower v/c condition (i.e., v/c ratio 0.7).

Table 5-3. Operational Performance of Various Intersection Layouts for Hybrid Gas Station

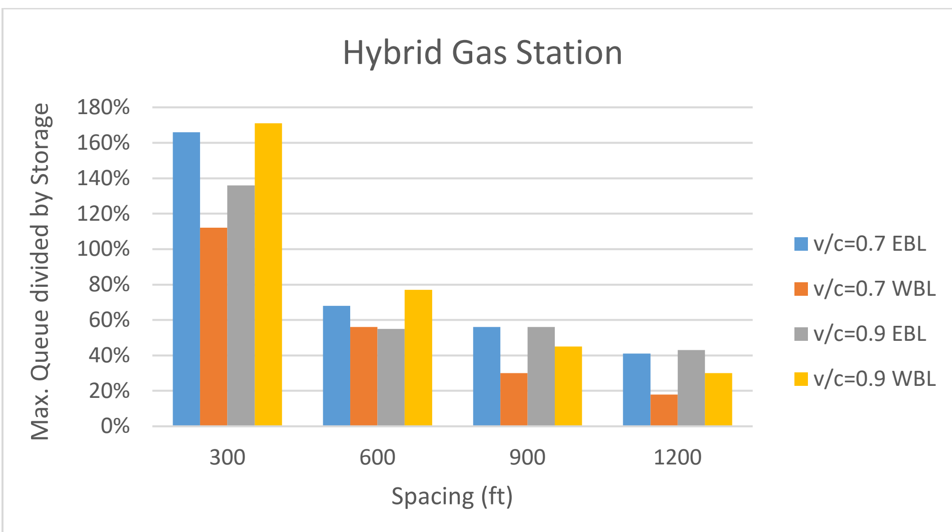
Intersection Layout	Spacing (ft)	Delay		Queue Length	
		Anticip. Impact	Movements that May Experience Significant Delay	Anticip. Impact	Movements that May Experience Significant Queueing
v/c = 0.7					
LR Offset	**-1200**	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	EBL, WBL, SBL	Low	n/a
	-300	Medium	EBL, WBL, NBL, SBL	Low	n/a
4-Leg	**0**	Medium	EBL, WBL, NBL, SBL	Low	n/a
RL Offset	**+300**	Medium	NBT, SBT, EBL, WBL	High	EBL, WBL
	+600	Medium	NBT, SBT, EBL, WBL	Low	n/a
	+900	High	EBL, EBT, NBT, WBL	Low	n/a
	+1200	High	EBL, EBT, NBT, WBL	Low	n/a
v/c = 0.9					
LR Offset	**-1200**	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-300	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
4-Leg	**0**	High	EBT, EBL, EBR, WBL, NBL, SBL	Low	n/a
RL Offset	**+300**	High	WBL, WBT, NBT, SBT, SBL	High	EBL, WBL
	+600	High	WBL, WBT, NBT, SBT, SBL	Medium	WBL
	+900	High	EBL, EBT, NBT, WBL, NBL, SBL	Low	n/a
	+1500	High	EBL, EBT, NBT, WBL, NBL, SBL	Low	n/a

5.2.2 Queue Length

Figure 5-4 presents graphical illustrations of the average through movement queue length divided by spacing ratio and maximum left-turn queue length divided by storage. From Figure 5-3(a), it was found that for both v/c levels, RL offsets are generally superior to LR offsets in terms of avoiding through movement queuing at signals. For the LR offset T-intersection, queue length to spacing ratio decreases with an increase of spacing. When designing a RL offset T-intersection for Hybrid Gas Station development scenario, Figure 5-3(b) shows that a RL offset T-intersection also requires a relatively longer stem spacing (e.g., > 600 ft) to prevent queue spillback; however, since trip generation rate of a Hybrid Gas Station is usually less than a Superstore shopping center, a spacing of 600 ft. was found to be sufficient.



(a) Average Through Movement Queue Length Divided by Spacing



(b) Maximum Left-Turn Movement Queue Length Divided by Storage

Figure 5-3. Queue Length under Various Spacing Levels for Hybrid Gas Station Development Scenario *Note: "EBTS" and "WBTS" refer to the eastbound/westbound through traffic between the stem.*

5.2.3 Delay

Figure 5-5 compares vehicle delay under two v/c levels for four movement groups: main street to main street, minor street to minor street, main street to minor street, and minor street to main street, respectively. Major findings from Figures 5-4(a) and 5-4(b) are listed as follows; detailed delay data for the Hybrid Gas Station development under two v/c levels are documented in Tables F2 and F7 of Appendix F, respectively.

Main Street to Main Street

- ✓ 4-leg intersection does not seem to benefit main street through movement
- ✓ LR offset generally outperform RL offset; no significant impacts of spacing was observed

Minor Street to Minor Street

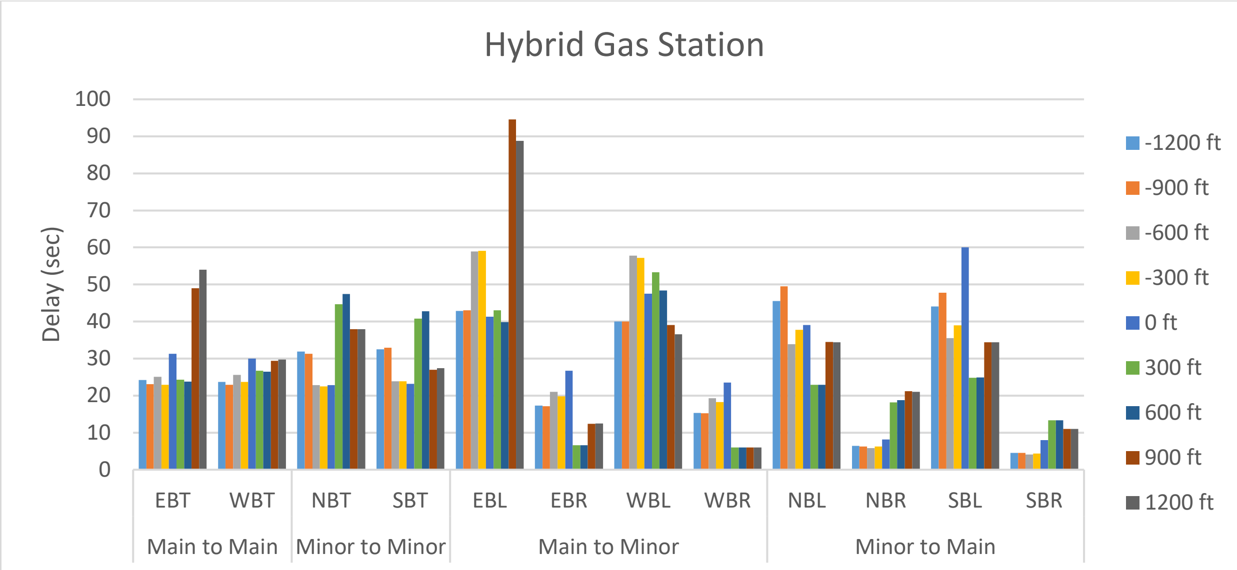
- ✓ 4-leg intersection has the lowest delay for minor street movements
- ✓ LR offset, delay decreases with increased spacing; however, for RL offset, delay increases with increased spacing

Main Street to Minor Street

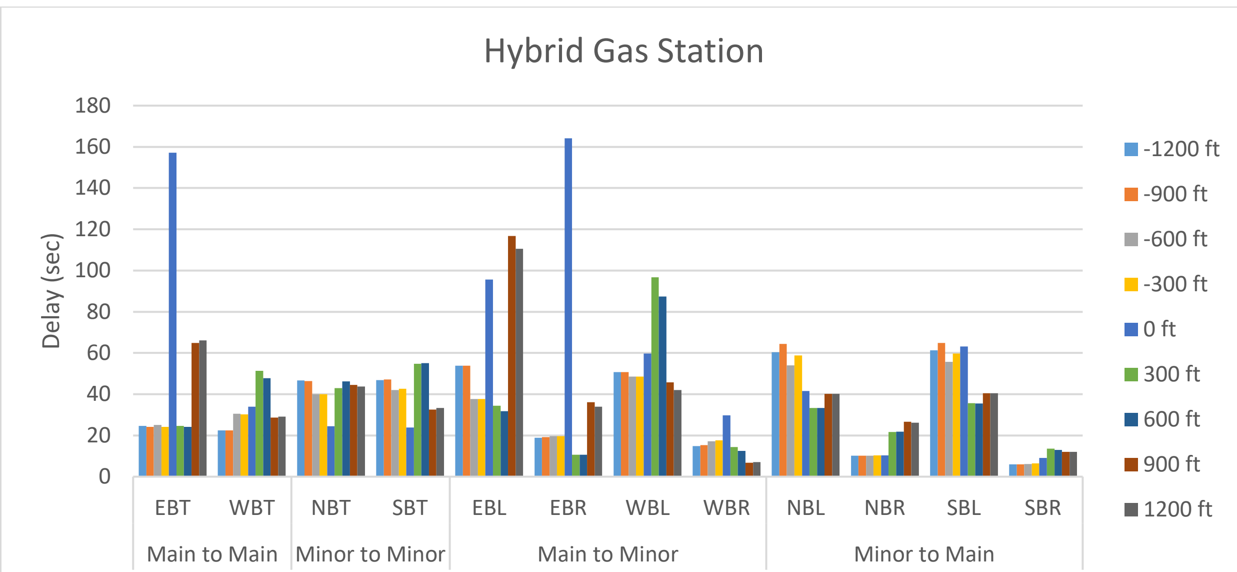
- ✓ Performance depends on movement; for left-turn movements, generally the LR offset outperforms RL offset, particularly when the spacing is relatively longer

Minor Street to Main Street

- ✓ For minor street left-turn movements, generally the RL offset is superior to LR offset. In addition, a shorter spacing level tends to result in less vehicle delay.



(a) v/c = 0.7



(b) v/c = 0.9

Figure 5-4. Movement-based Vehicle Delay under Various Spacing Levels for Hybrid Gas Station Development Scenario

5.3 Residential Area

5.3.1 Anticipated Service Impact

The qualitative description of the anticipated service impact and movements that may experience significant impacts for residential areas are presented in Tables 5-4 and 5-5, respectively.

This research finds that when developing a residential area with a relatively low v/c ratio condition, an LR offset T-intersection with short-to-long spacing (e.g., longer than 300 ft.) could accommodate both AM and PM traffic. When the v/c ratio is high, the LR offset T-intersection again provides better results with short-to-long spacing (e.g., longer than 300 ft.) could accommodate traffic under both AM and PM periods. To accommodate the most challenging situation, this research recommends a LR offset T-intersection with a spacing longer than 300 ft. for the residential area development type. Even so, the RL Offset could be considered in instances where lower v/c ratios are present.

The Analysis of Variance (ANOVA) statistical test on the delay measure of major street through and left turn movements for AM and PM scenarios are documented in Tables E3 and E4 of Appendix E, respectively. Results showed that the recommended offset T-intersection configurations outperforms the regular 4-Leg intersection at 0.05 significance level.

Table 5-4. Operational Performance of Various Intersection Layouts for Residential Area Development Scenario AM Period

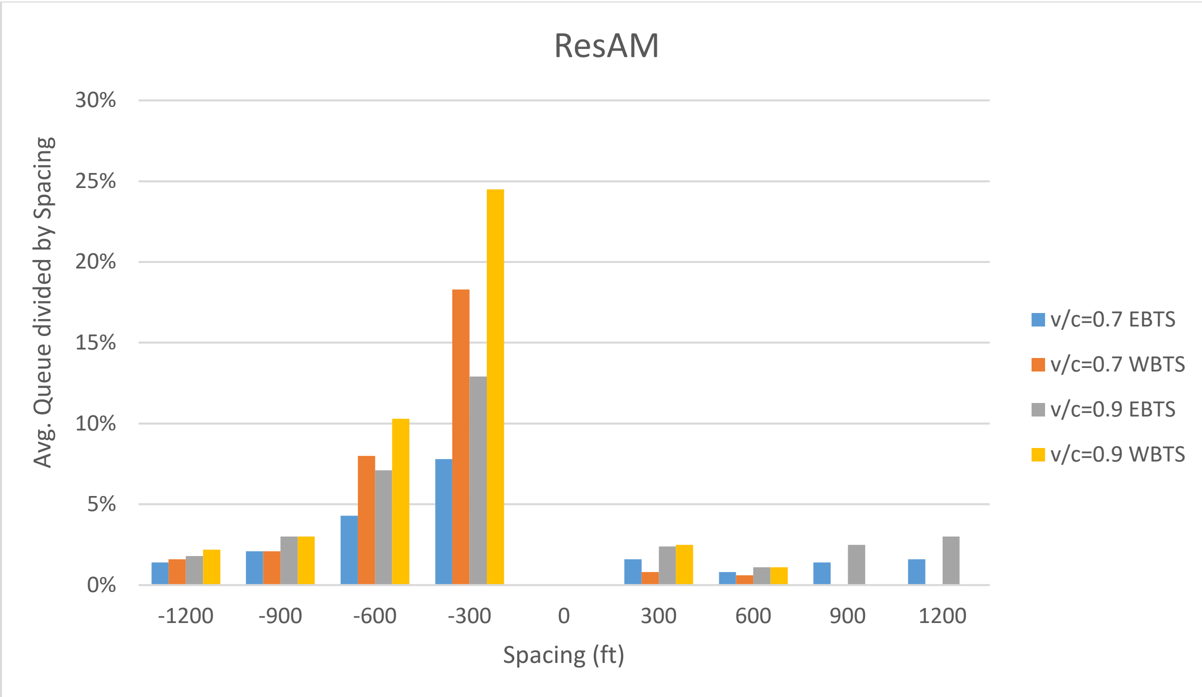
v/c = 0.7					
Intersection Layout	**Spacing (ft)**	**Delay**		**Queue Length**	
		Anticip. Impact	**Movements that May Experience Significant Delay**	**Anticip. Impact**	**Movements that May Experience Significant Queueing**
LR Offset	**-1200**	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	NBT, WBL, NBL, SBL	Low	n/a
	-300	Medium	NBT, WBL, NBL, SBL	Low	n/a
4-Leg	**0**	Medium	EBL, WBL, NBL, SBL	Low	n/a
RL Offset	**+300**	Medium	SBT, EBL, WBL	High	WBL
	+600	Medium	NBT, SBT, EBL, WBL	Medium	WBL
	+900	High	EBL, EBT, WBT, WBL, NBL	Low	n/a
	+1200	Medium	EBL, EBT, WBT, WBL, NBL	Low	n/a
v/c = 0.9					
LR Offset	**-1200**	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-300	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
4-Leg	**0**	High	EBT, EBL, EBR, NBL, SBL	Low	n/a
RL Offset	**+300**	High	WBL, WBT, EBL, NBL	High	WBL
	+600	High	WBL, WBT, NBT, SBT, EBL, NBL	High	WBL
	+900	High	WBT, EBL, WBL, WBR, EBT, NBL	Low	n/a
	+1200	High	WBT, EBL, WBL, WBR, EBT, SBT, NBL	Low	n/a

Table 5-5. Operational Performance of Various Intersection Layouts for Residential Area Development Scenario PM Period

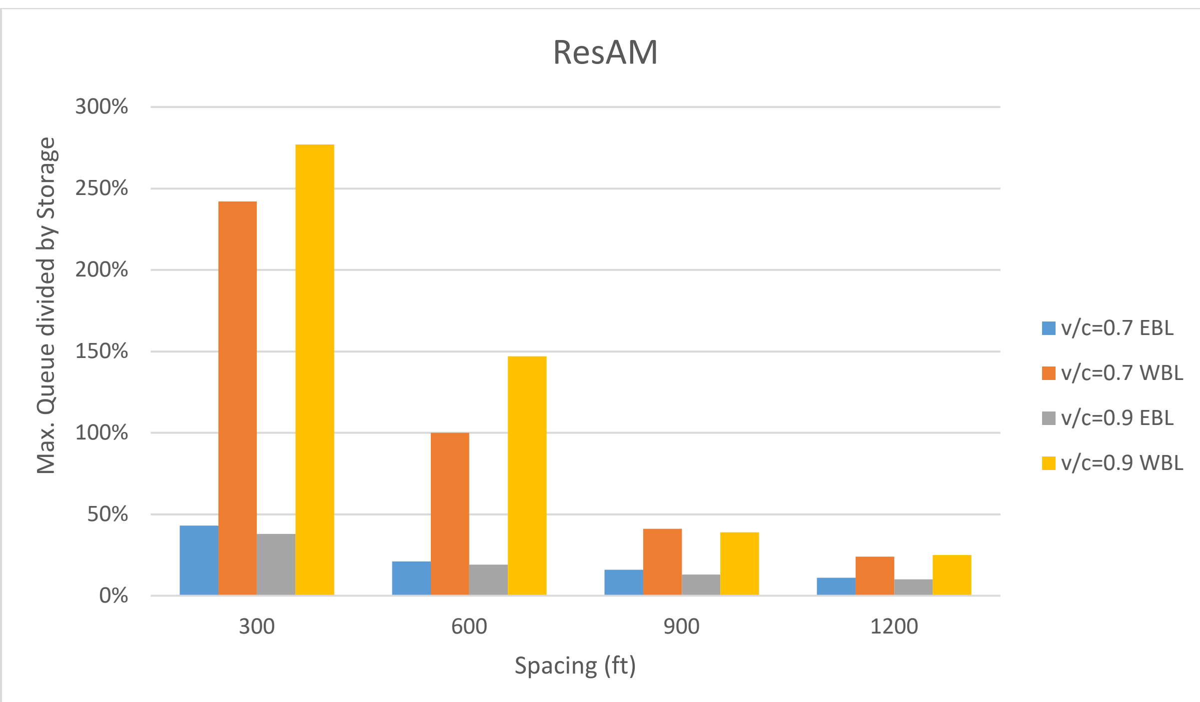
v/c = 0.7					
Intersection Layout	**Spacing (ft)**	**Delay**		**Queue Length**	
		Anticip. Impact	**Movements that May Experience Significant Delay**	**Anticip. Impact**	**Movements that May Experience Significant Queueing**
LR Offset	**-1200**	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-300	Medium	EBL, WBL, NBL, SBL	Low	n/a
4-Leg	**0**	Medium	EBL, WBL, NBL, SBL	Low	n/a
RL Offset	**+300**	Medium	WBT, SBT, WBL	High	WBL, EBL
	+600	Medium	WBT, SBT, WBL	Low	n/a
	+900	High	EBL, EBT, WBL	Low	n/a
	+1200	High	EBL, EBT, WBL	Low	n/a
v/c = 0.9					
LR Offset	**-1200**	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	WBT, NBT, SBT, WBL, NBL, SBL	Low	n/a
	-300	Medium	WBT, NBT, SBT, WBL, NBL, SBL	Low	n/a
4-Leg	**0**	High	EBT, EBL, EBR, WBL, NBL, SBL	Low	n/a
RL Offset	**+300**	High	WBT, WBL, NBT, SBT, WBR	High	EBL, WBL
	+600	High	WBT, WBL, NBT, SBT	Medium	WBL
	+900	High	EBT, EBL, EBR, NBT, WBL, NBL	Low	n/a
	+1200	High	EBT, EBL, EBR, NBT, WBL, NBL	Low	n/a

5.3.2 Queue Length

Figures 5-5 and 5-6 illustrate the queue length measures for Residential area scenarios with AM period and PM period traffic, respectively. It was found that for both AM and PM periods, RL offsets are generally superior to LR offsets in terms of avoiding through movement queuing at signals. For the LR offset T-intersection, queue length to spacing ratio decrease with the increase of spacing. When designing an RL offset T-intersection for a Residential area, special attention should be paid to the WBL movement. Generally speaking, under a low v/c ratio (e.g., lower than 0.7), a spacing that is larger than 600 ft. was found to be sufficient to contain the vehicle queue of the WBL movement. When the v/c ratio is larger than 0.7, a longer spacing (e.g., longer than 900 ft.) is recommended.

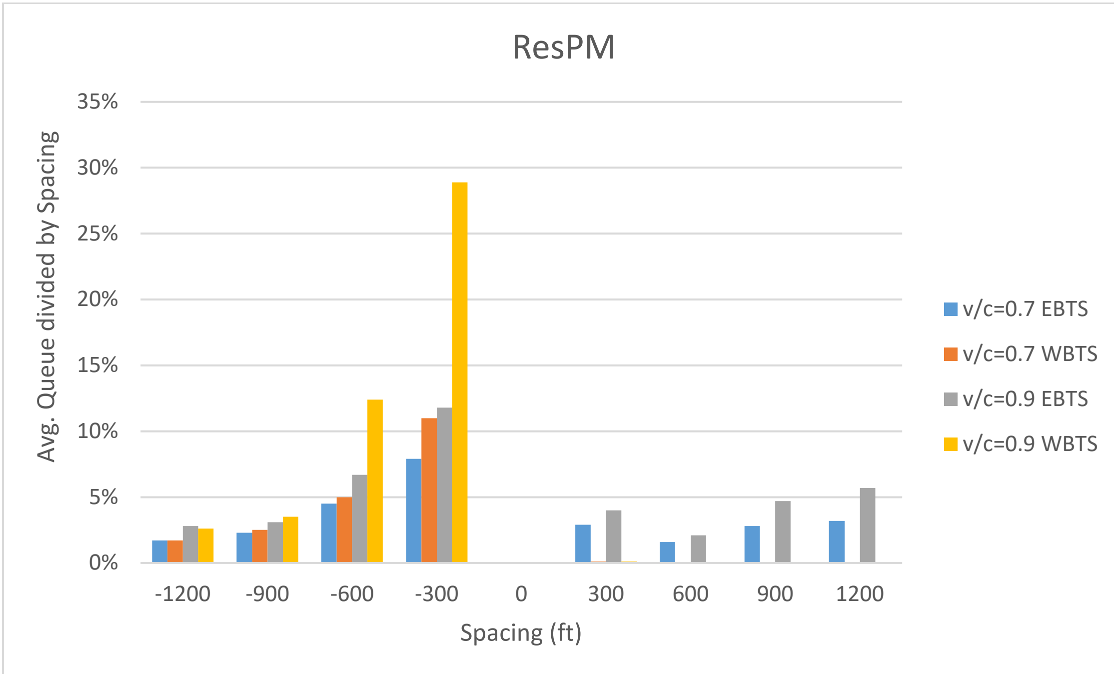


(a) Average Through Movement Queue Length Divided by Spacing

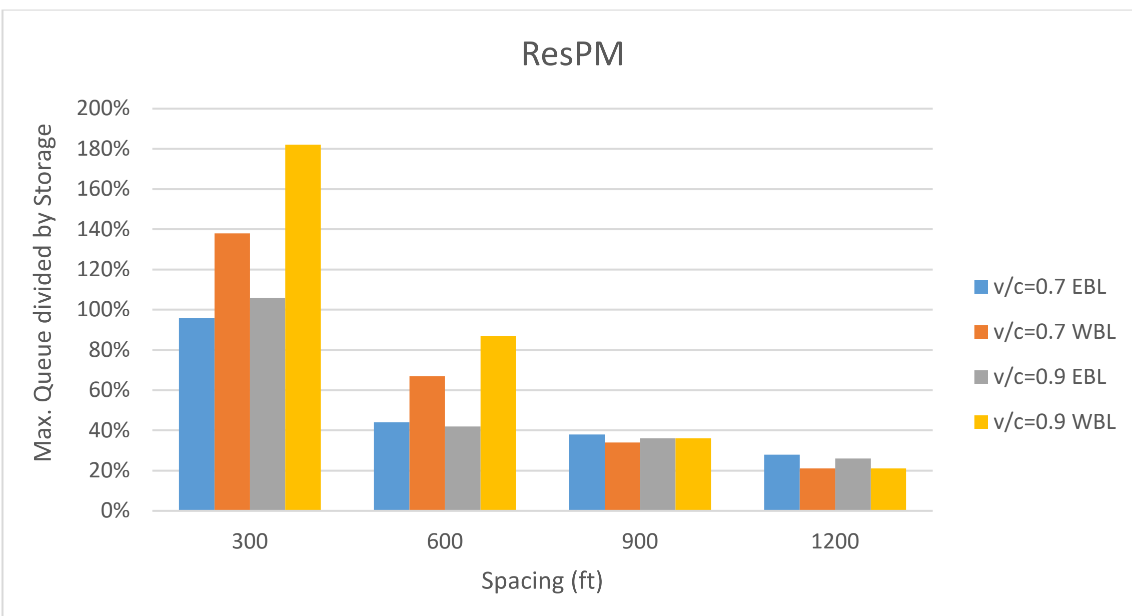


(b) Maximum Left-Turn Movement Queue Length Divided by Storage

Figure 5-5. Queue Length under Various Spacing Levels for Residential Area Development AM Scenario. *Note: "EBTS" and "WBTS" refer to the eastbound/westbound through traffic between the stem.*



(a) Average Through Movement Queue Length Divided by Spacing



(b) Maximum Left-Turn Movement Queue Length Divided by Storage

Figure 5-6. Queue Length under Various Spacing Levels for Residential Area Development PM Scenario. *Note: "EBTS" and "WBTS" refer to the eastbound/westbound through traffic between the stem.*

5.3.3 Delay

Figures 5-7 and 5-8 presented the comparisons of vehicle delays for a Residential development during AM period and PM period traffic conditions, respectively. Major findings from the comparisons are listed as follows; detailed delay data for the Residential development AM period under the v/c levels are documented in Tables F3 and F8 of Appendix F. Vehicle delay for Residential development PM period are documented in Tables F4 and F9, respectively.

Main Street to Main Street

- ✓ LR offset is superior to RL offset and 4-leg intersection; under a high v/c ratio condition, 4-leg intersection tends to bring significant delay to the EBT movement
- ✓ For LR offset, generally a longer spacing will result in a lower vehicle delay for both EBT and WBT movements
- ✓ RL offset with a long spacing is not recommended since it would bring significant delay to both EBT and WBT movements

Minor Street to Minor Street

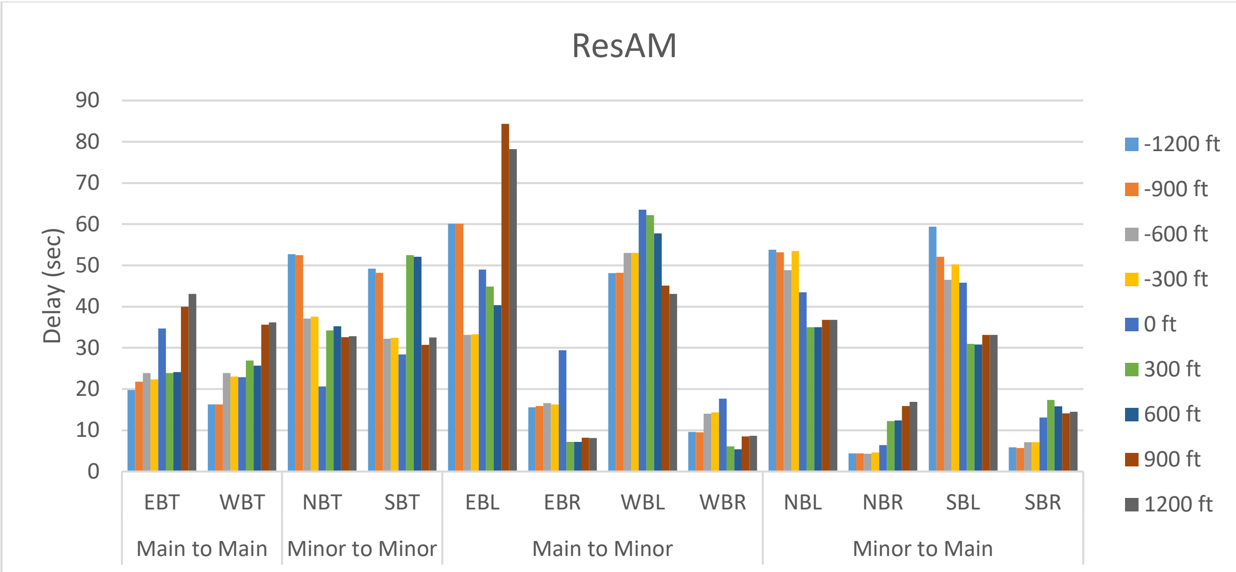
- ✓ 4-leg standard intersection has the lowest delay for minor street movements
- ✓ LR offset, delay generally increases with increased spacing
- ✓ RL offset, delay decreases with increased spacing

Main Street to Minor Street

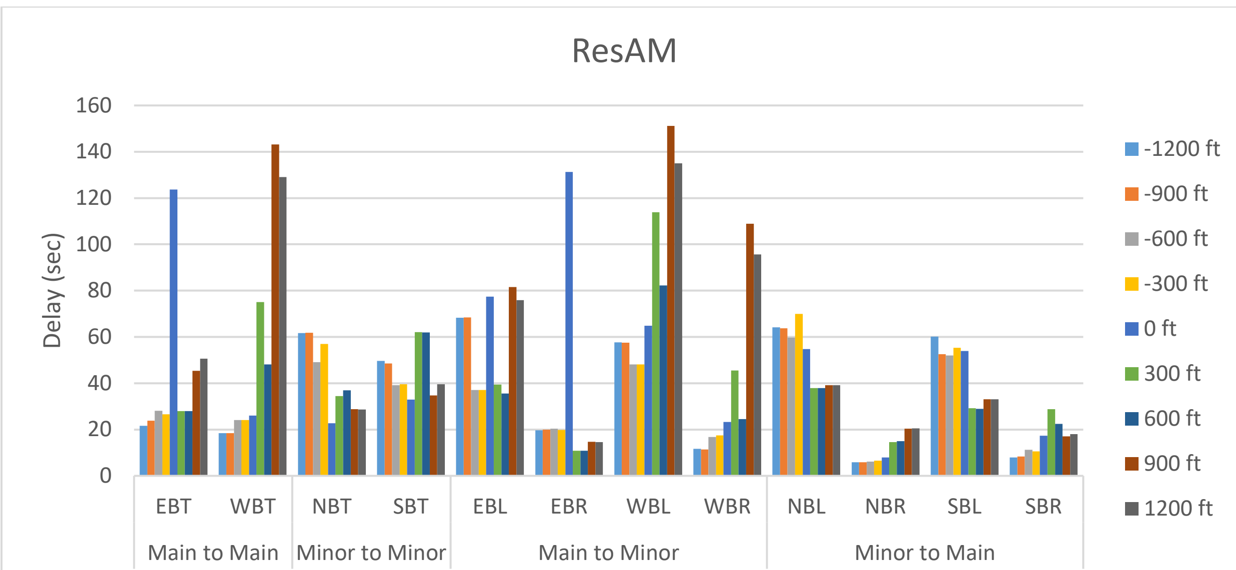
- ✓ Performance depends on movement; right turns have lower delays than left turns, while 4-leg standard intersection tends to bring significant delay to the EBR movement
- ✓ For EBL movements, a short spacing will lead to less delay

Minor Street to Main Street

- ✓ For minor street left turn movements, RL offset is superior to LR offset and 4-leg standard intersection; and a shorter spacing tends to result in a lower delay
- ✓ LR offset is particularly beneficial to minor street right-turn movements

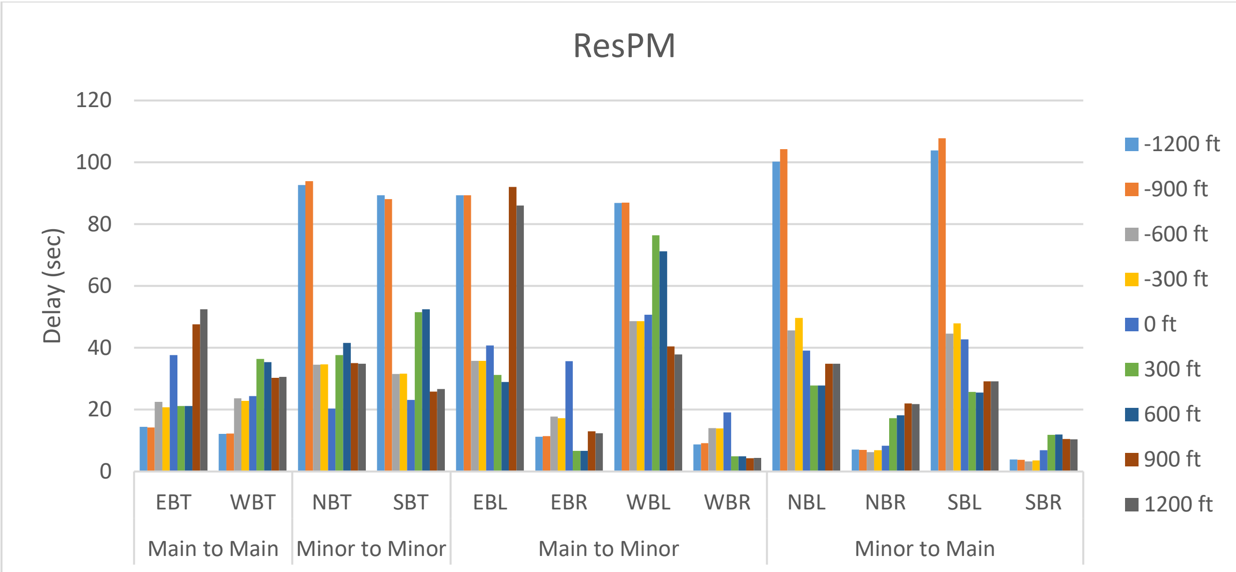


(a) v/c = 0.7

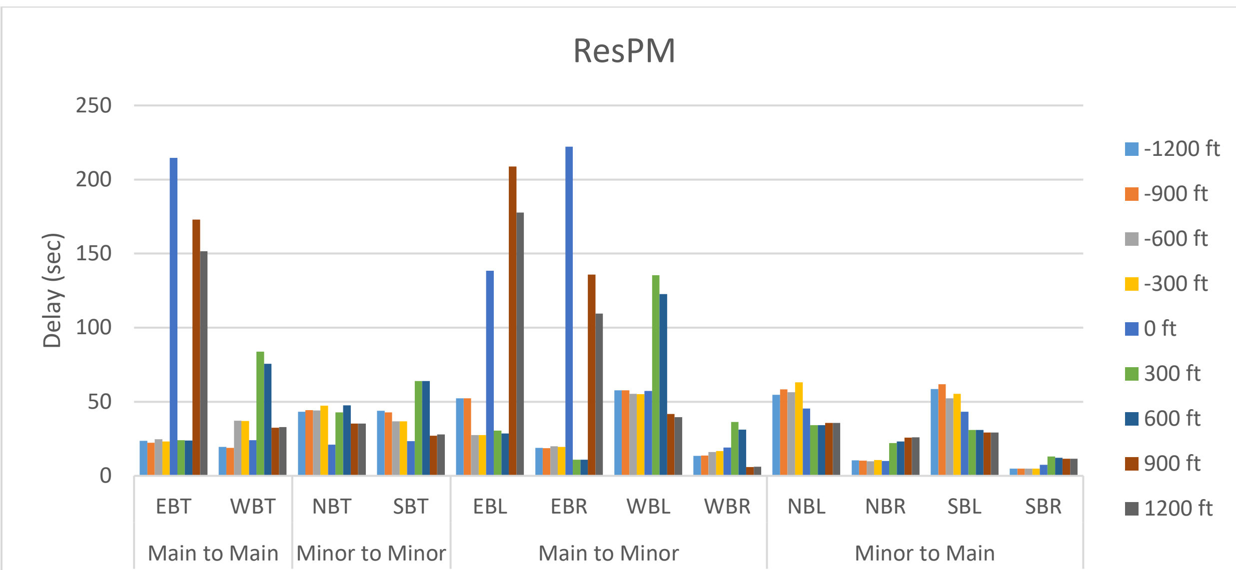


(b) v/c = 0.9

Figure 5-7. Movement-based Vehicle Delay under Various Spacing Levels for Residential Area Development Scenario AM Period



(a) v/c = 0.7



(b) v/c = 0.9

Figure 5-8. Movement-based Vehicle Delay under Various Spacing Levels for Residential Area Development Scenario PM Period

5.4 Realign

5.4.1 Anticipated Service Impact

The qualitative description of the anticipated service impact and movements that may experience significant impacts for the Realign scenario are presented in Table 5-6. This research team recommends a LR offset T-intersection with a relatively longer spacing for a roadway realignment scenario.

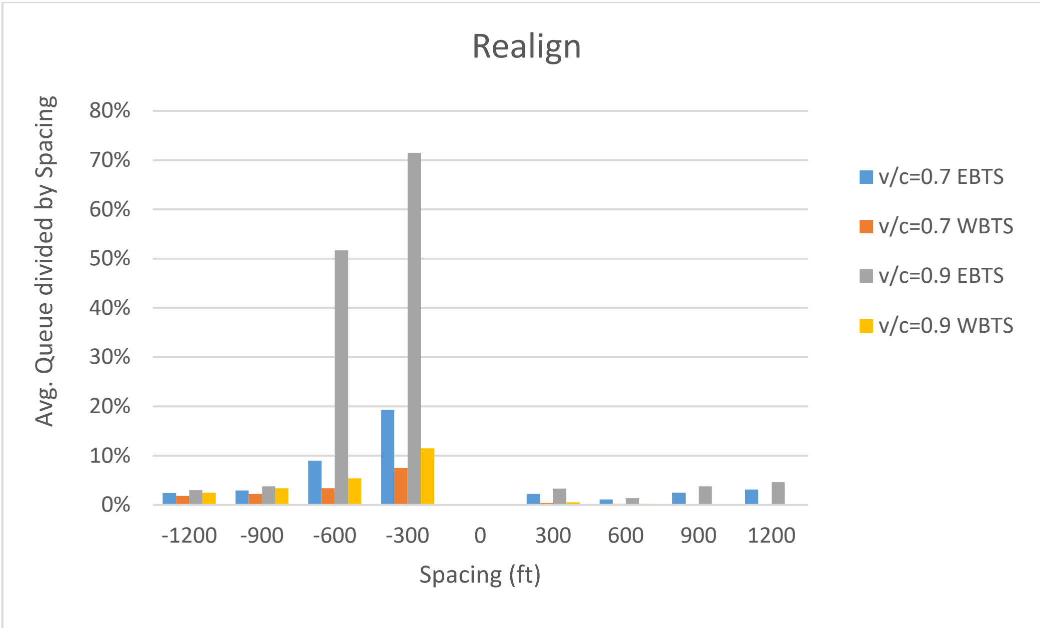
The Analysis of Variance (ANOVA) statistical test on the delay measure of major street through and left turn movements is listed in Table E5 of Appendix E. Results indicated that the recommended offset T-intersection design generally outperforms the 4-leg intersection design expected for the eastbound left-turn movements under a v/c ratio of 0.7.

Table 5-6. Operational Performance of Various Intersection Layouts for Realign Scenario

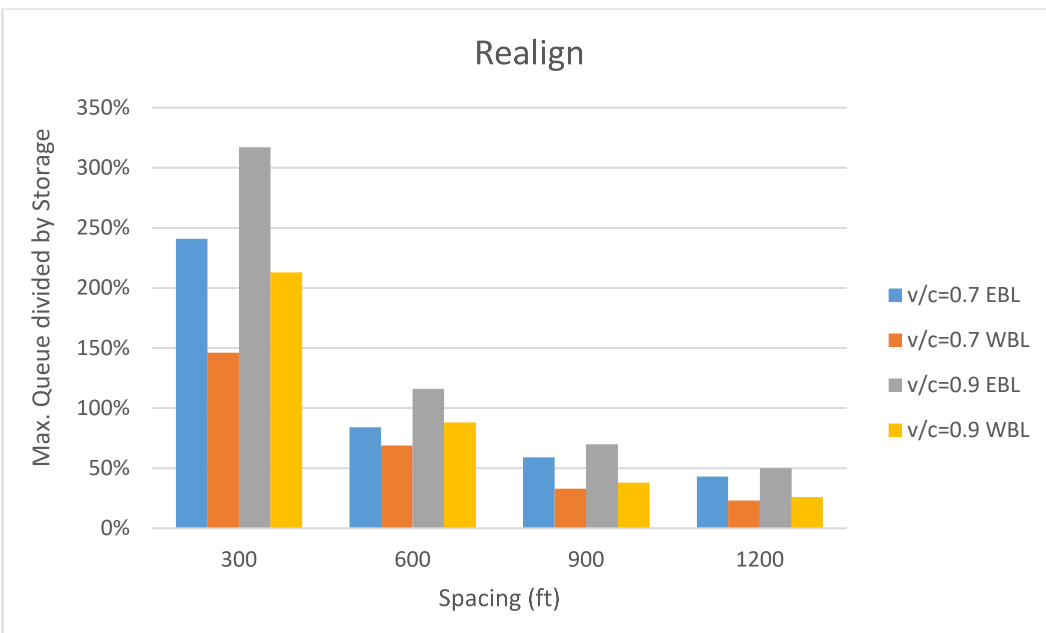
Intersection Layout	Spacing (ft)	Delay		Queue Length	
		Anticip. Impact	Movements that May Experience Significant Delay	Anticip. Impact	Movements that May Experience Significant Queueing
v/c = 0.7					
LR Offset	-1200	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	EBL, WBL, NBL, SBL	Low	n/a
	-600	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-300	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
4-Leg	0	Medium	EBL, WBL, NBL, SBL	Low	n/a
RL Offset	+300	Medium	NBT, SBT, EBL, WBL	High	EBL, WBL
	+600	Medium	NBT, SBT, EBL, WBL	Medium	EBL
	+900	High	EBL, EBT, NBT, WBL	Low	n/a
	+1500	High	EBL, EBT, NBT, WBL	Low	n/a
v/c = 0.9					
LR Offset	-1200	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-900	Medium	NBT, SBT, EBL, WBL, NBL, SBL	Low	n/a
	-600	High	EBT, SBT, SBL, EBL, EBR, NBL	Low	n/a
	-300	High	EBT, SBT, SBL, EBL, EBR, NBL	Low	n/a
4-Leg	0	Medium	EBT, EBL, EBR, WBL, NBL, SBL	Low	n/a
RL Offset	+300	High	WBL, NBT, SBT, EBL, SBL	High	EBL, WBL
	+600	Medium	WBL, NBT, SBT, EBL, SBL	Medium	EBL, WBL
	+900	High	EBT, EBL. EBR, NBT, WBL, SBL	Low	n/a
	+1500	High	EBT, EBL. EBR, NBT, WBL, SBL	Low	n/a

5.4.2 Queue Length

Figure 5-9 presents graphical illustrations of the average through movement queue length divided by spacing ratio and maximum left-turn queue length divided by storage. From Figure 5-9(a), it was found that RL offsets are generally superior to LR offsets, but both designs provided sufficient storage to avoid spillback for through movements between the stems. For LR offset T-intersections, queue length to spacing ratio decreases with an increase in spacing. Under a high v/c condition, the EBT movement tends to have a higher risk of queue spillback when using a short spacing. When designing an RL offset T-intersection for the Realign scenario, it seems that a spacing larger than 600 feet could accommodate low v/c ratio conditions but may create left turn storage concerns when the v/c ratio approaches 0.9 or more.



(a) Average Through Movement Queue Length Divided by Spacing



(b) Maximum Left-Turn Movement Queue Length Divided by Storage

Figure 5-9. Queue Length under Various Spacing Levels for Realign Scenario for Realign Scenario. *Note: "EBTS" and "WBTS" refer to the eastbound/westbound through traffic between the stem.*

5.4.3 Delay

Figure 5-10 compares vehicle delay under two v/c levels for four movement groups: main street to main street, minor street to minor street, main street to minor street, and minor street to main street, respectively. Major findings are listed as follows; detailed delay data for the Realign scenario under two v/c levels are documented in Tables F5 and F10 of Appendix F, respectively.

Main Street to Main Street

- ✓ LR offset generally has a smaller delay than RL offset and 4-leg standard intersection. In addition, a longer spacing generally resulted in a lower delay.

Minor Street to Minor Street

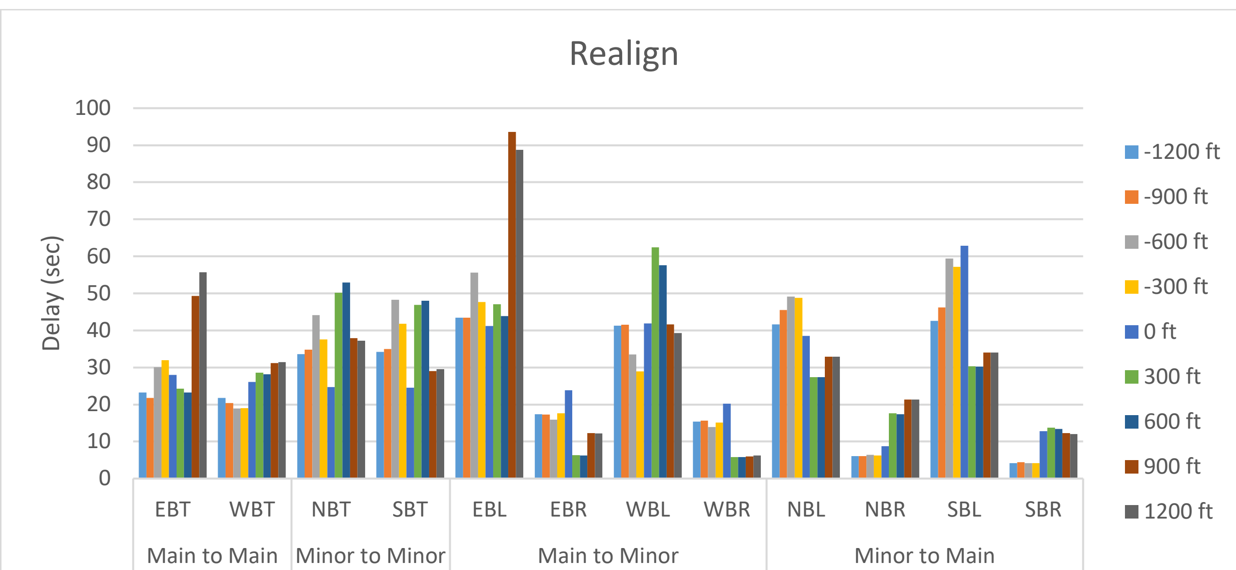
- ✓ 4-leg intersection has the lowest delay for minor street movements
- ✓ For both LR and RL offsets, delay tends to decrease with increased spacing.

Main Street to Minor Street

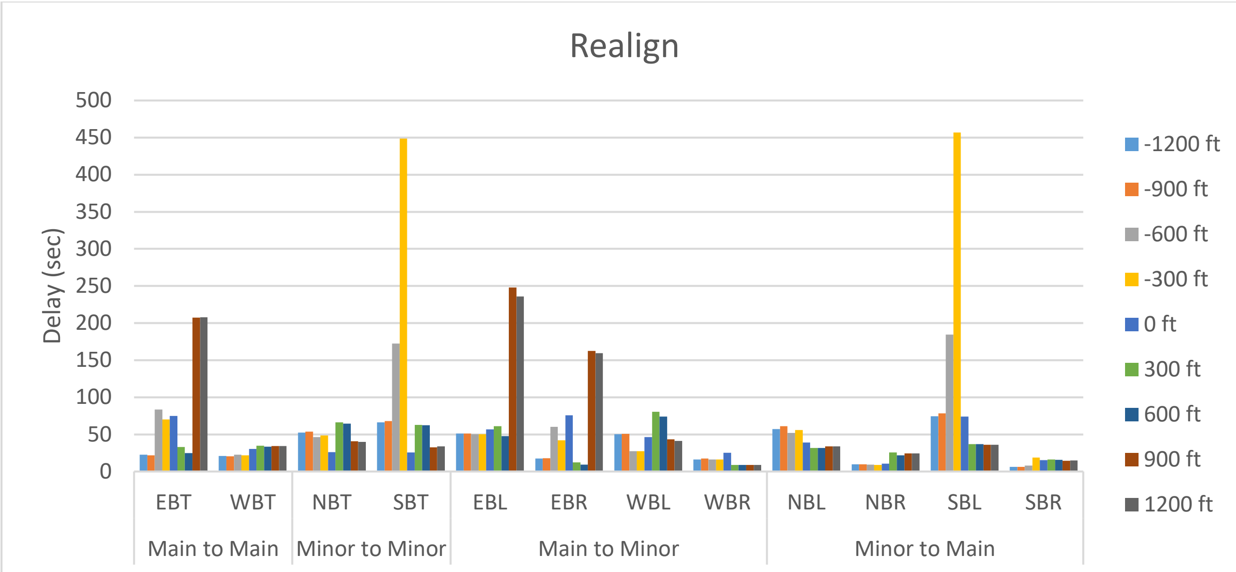
- ✓ Generally, the LR offset with a shorter spacing benefits left-turn movements

Minor Street to Main Street

- ✓ RL offset is superior to LR offset for minor street left turn movements, particularly when spacing is short
- ✓ LR offset is beneficial to minor street right-turn movements



(a) v/c =0.7



(b) v/c =0.9

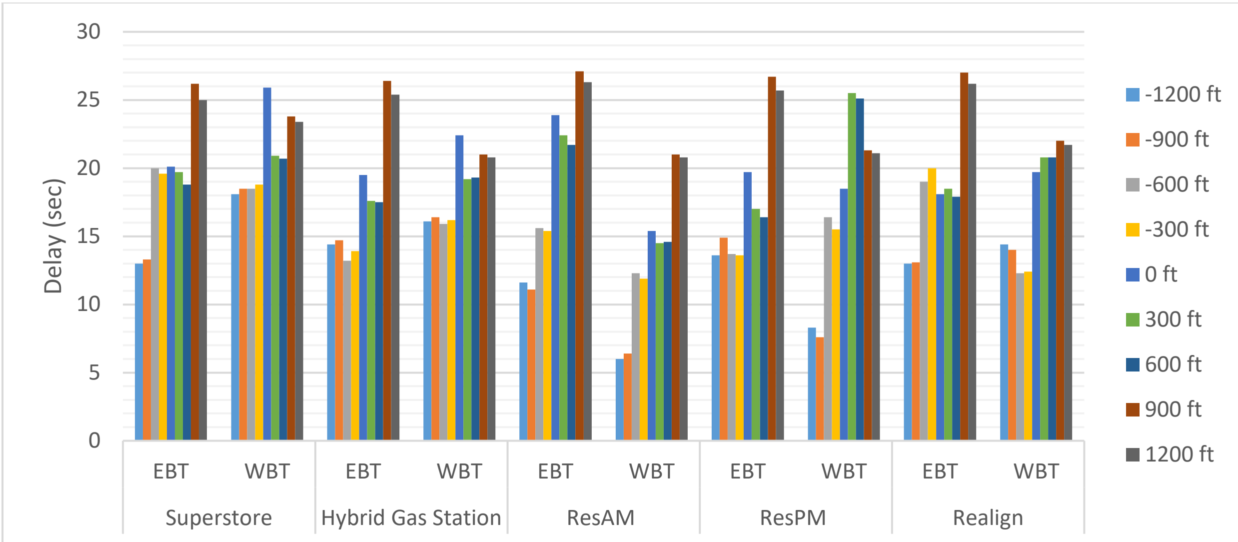
Figure 5-10. Movement-based Vehicle Delay under Various Spacing Levels for Realign Scenario

5.5 Bicycle and Pedestrian Delay

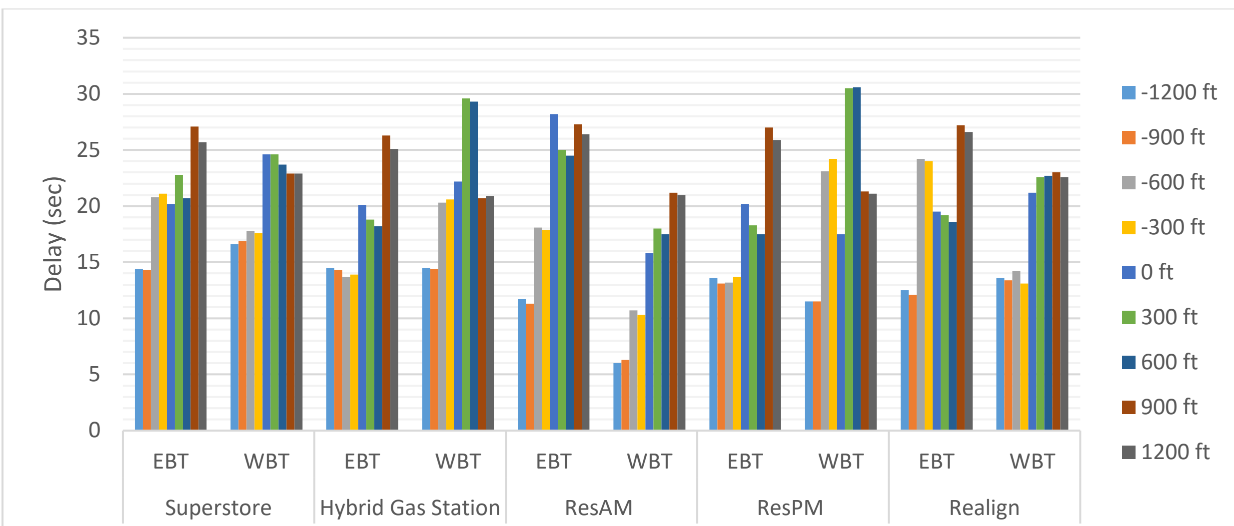
5.5.1 Bicycle Delay

Figures 5-11 to 5-14 compare bicycle delay under two v/c levels for four movement groups: main street to main street, minor street to minor street, main street to minor street, and minor street to main street, respectively. Overall, the LR design tends to reduced bicycle delay over the RL design, with exceptions noted below. Detailed simulation results are attached in Appendix F.

Main Street to Main Street: Simulation results reveals that LR offset outperformed RL offset in terms of reducing bicycle delay for main street through movements. For LR offset, generally a longer spacing has a lower delay, while for RL offset, a shorter spacing has a lower delay.



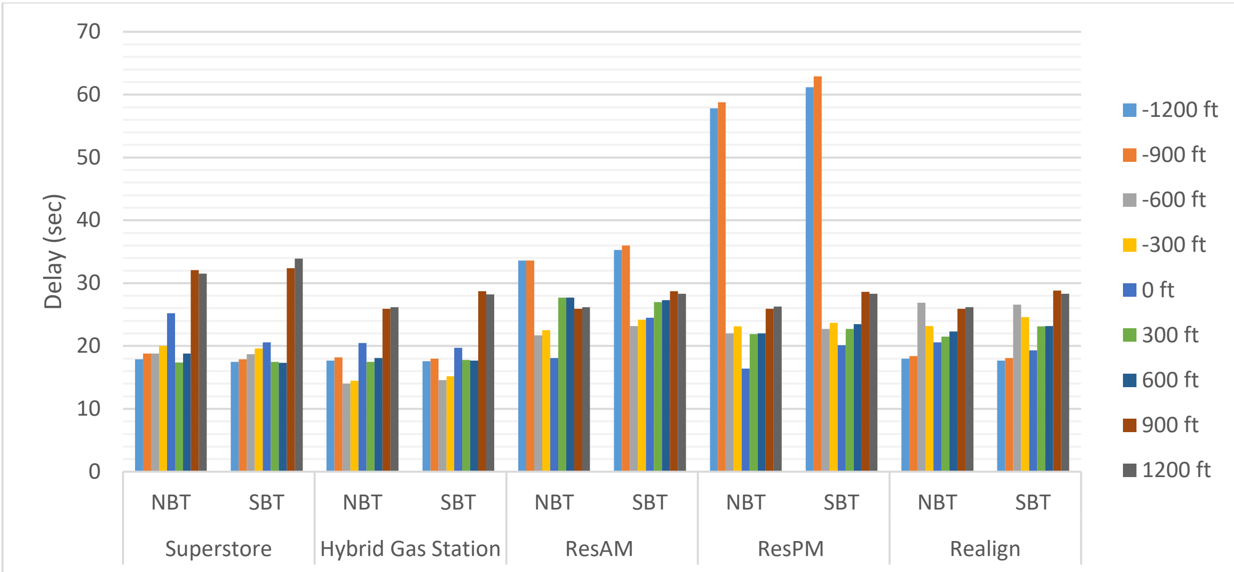
(a) Main Street to Main Street (v/c=0.7)



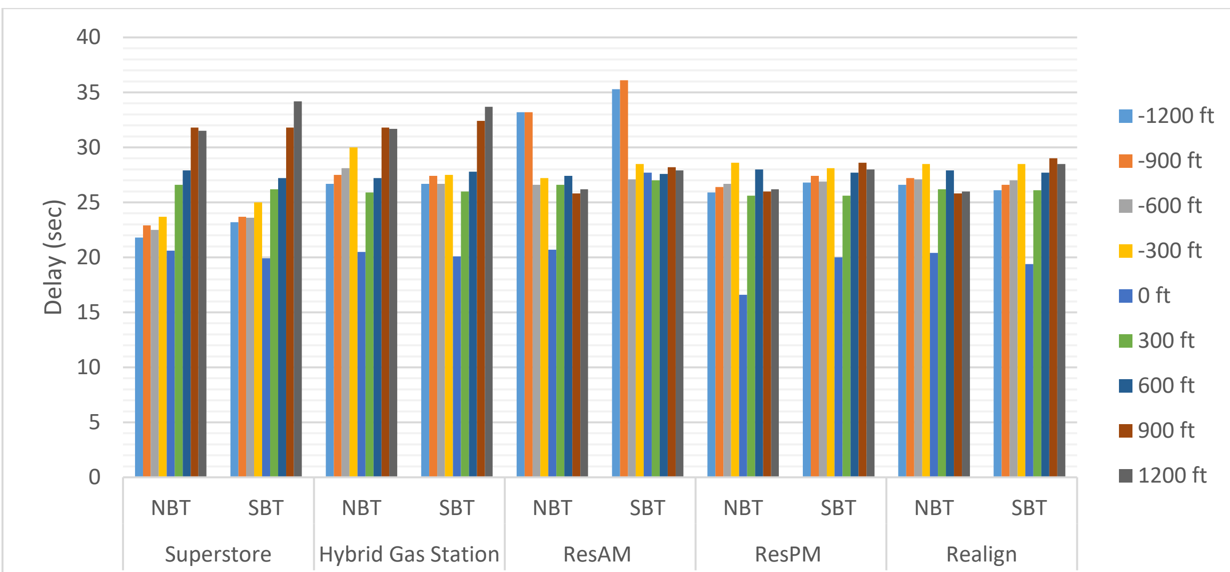
(b) Main Street to Main Street (v/c=0.9)

Figure 5-11. Comparison of Bicycle Delay for Main Street Through Movements

Minor Street to Minor Street: Simulation results reveals that for the minor street through movement, bicycle delay tends to be affected by the signal timing plan tested during the simulation experiment. For a given development type, the +900 ft and +1200 ft, as well as the -900 ft and -1200 ft, spacings used the same signal phasing schemes. This can explain much of the delay increase seen in those spacings. In addition, an offset T-intersection with a high v/c ratio tends to have a higher bicycle delay than a 4-leg intersection.



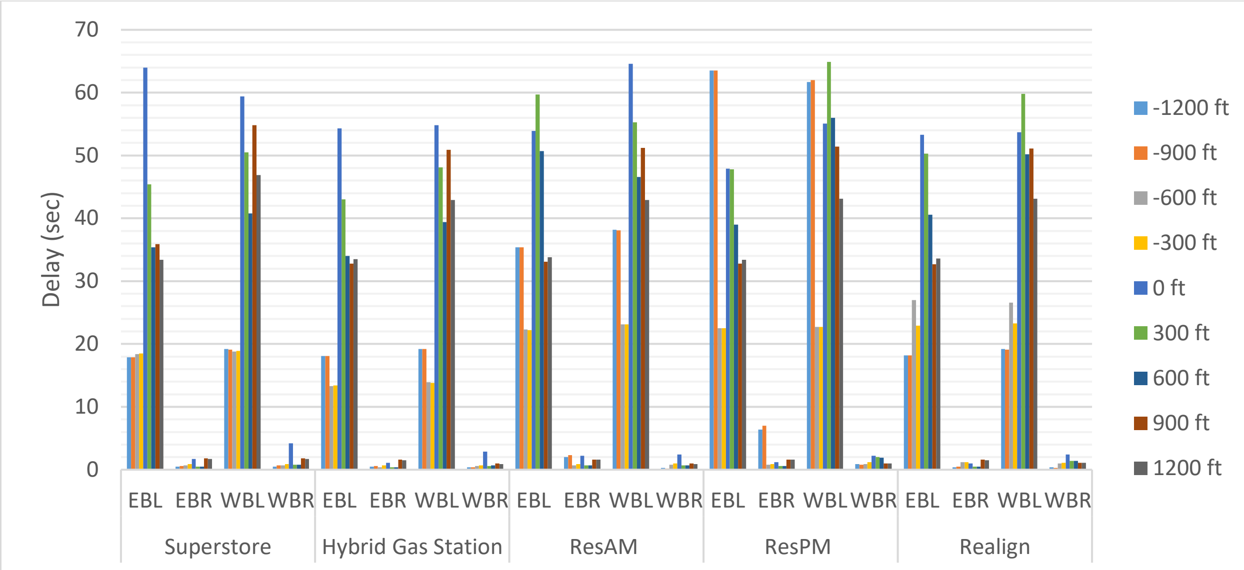
(a) Minor Street to Minor Street (v/c=0.7)



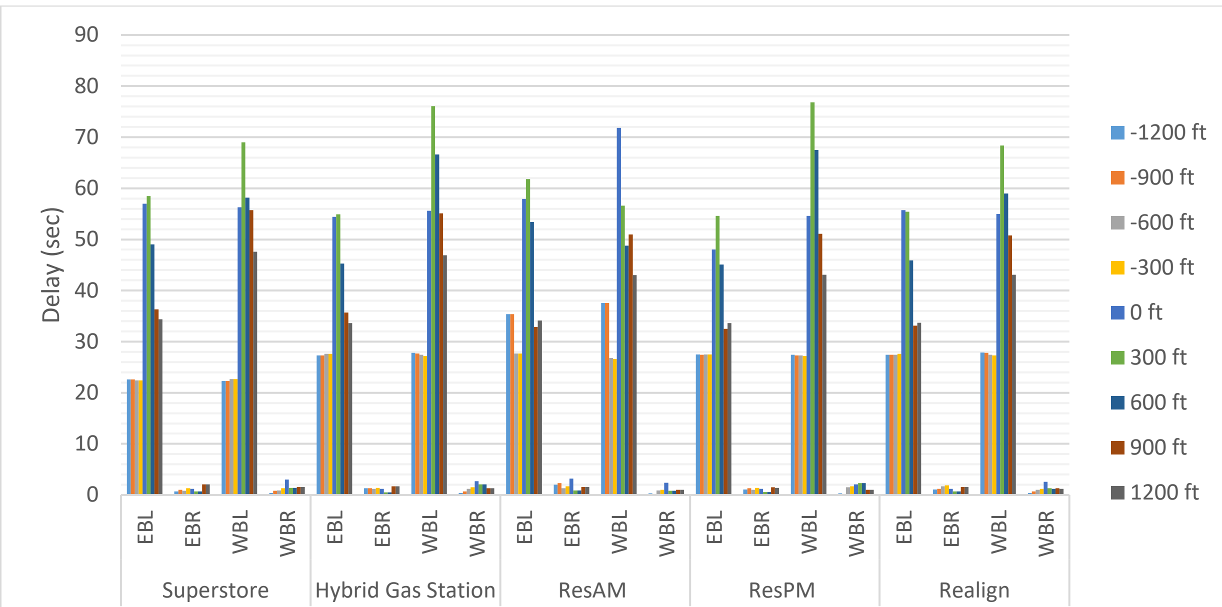
(b) Minor Street to Minor Street (v/c=0.9)

Figure 5-12. Comparison of Bicycle Delay for Minor Street Through Movements

Main Street to Minor Street: For main street left turn and right turn movements, this research found that under most scenarios, offset T-intersections are superior to 4-leg standard intersections and the LR offset is superior to the RL offset. For the LR offset, a shorter stem spacing tends to reduce bicycle delay, while for RL offset, a longer stem spacing will reduce bicycle delay.



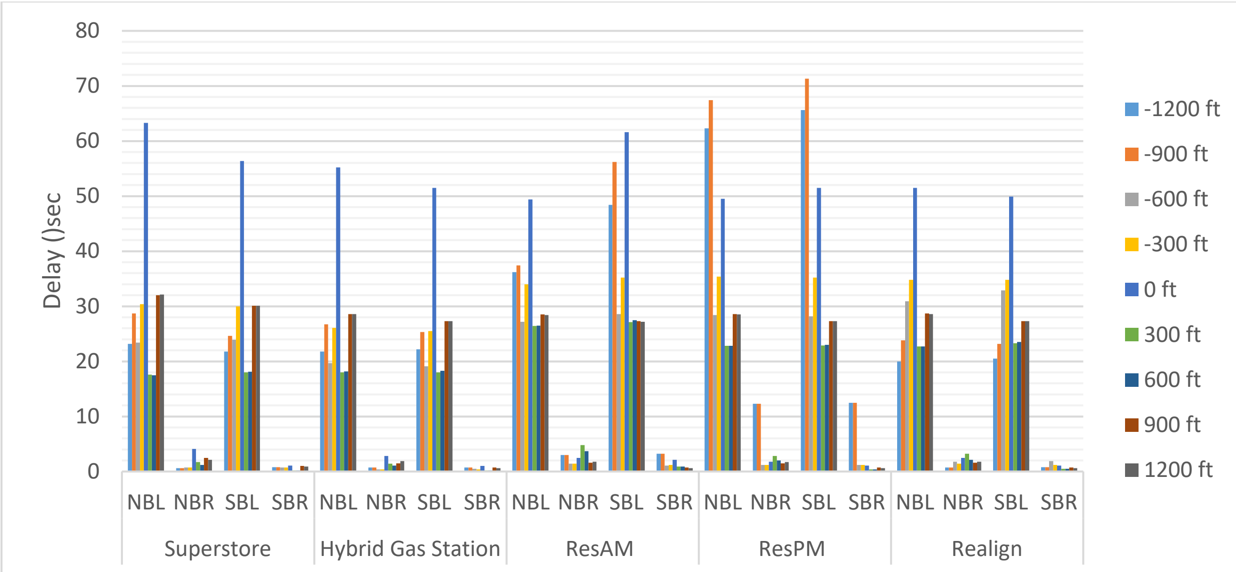
(a) Main Street to Minor Street (v/c=0.7)



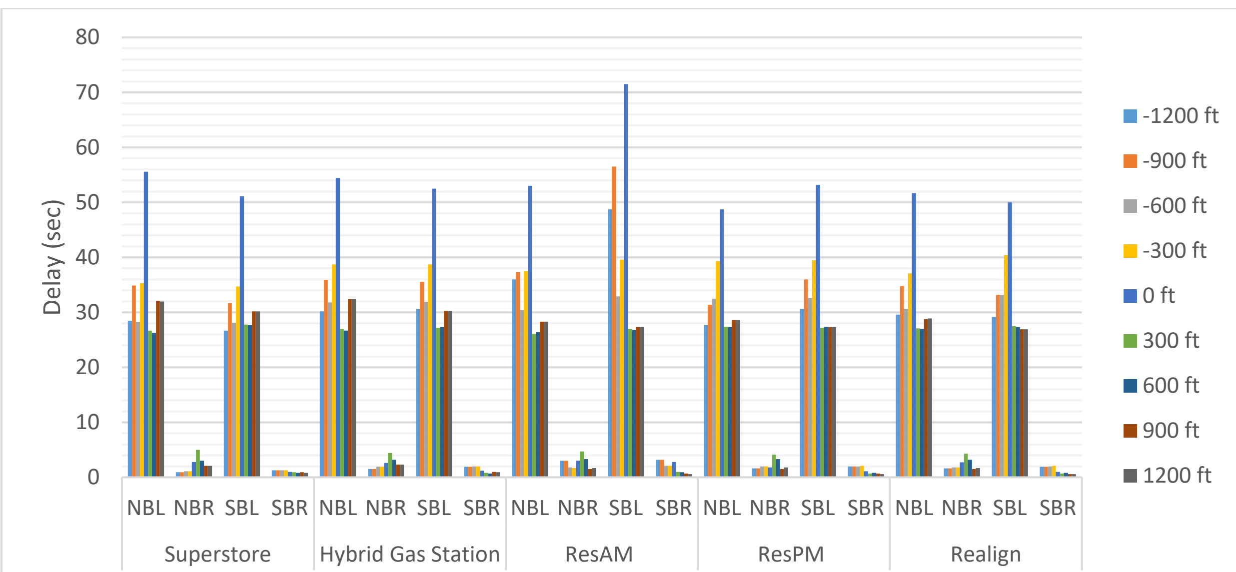
(b) Main Street to Minor Street (v/c=0.9)

Figure 5-13. Comparison of Bicycle Delay for Main Street to Minor Street Movements

Minor Street to Main Street: For minor street left turn and right turn movements, simulation results revealed that 4-Leg standard intersections result in the highest bicycle delay, particularly under high v/c scenarios.



(a) Minor Street to Main Street (v/c=0.7)

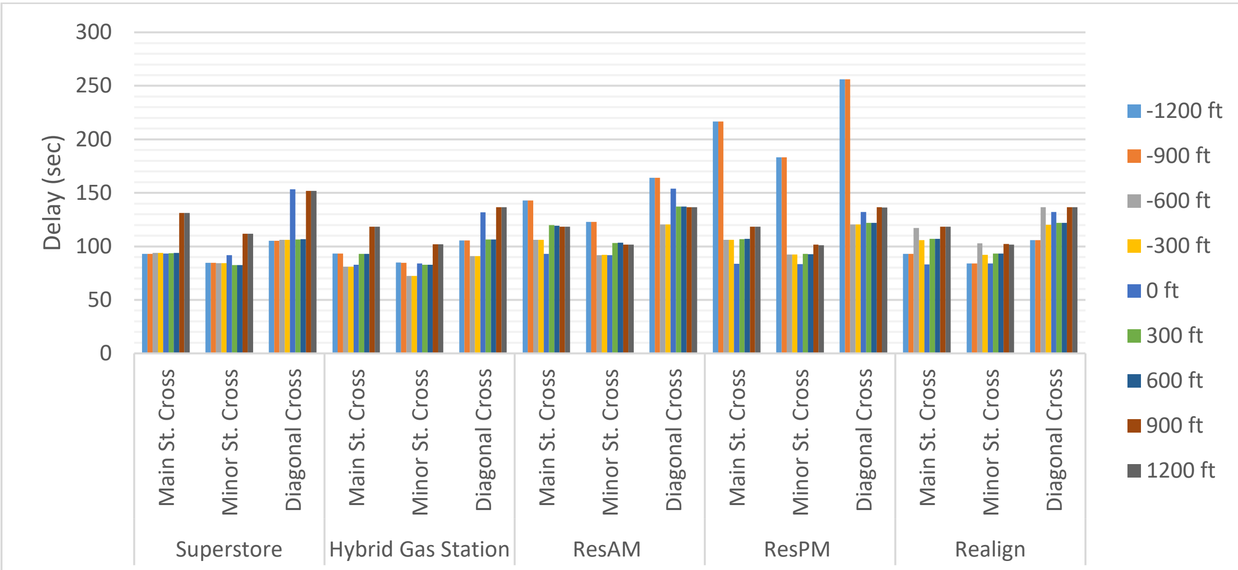


(b) Minor Street to Main Street (v/c=0.9)

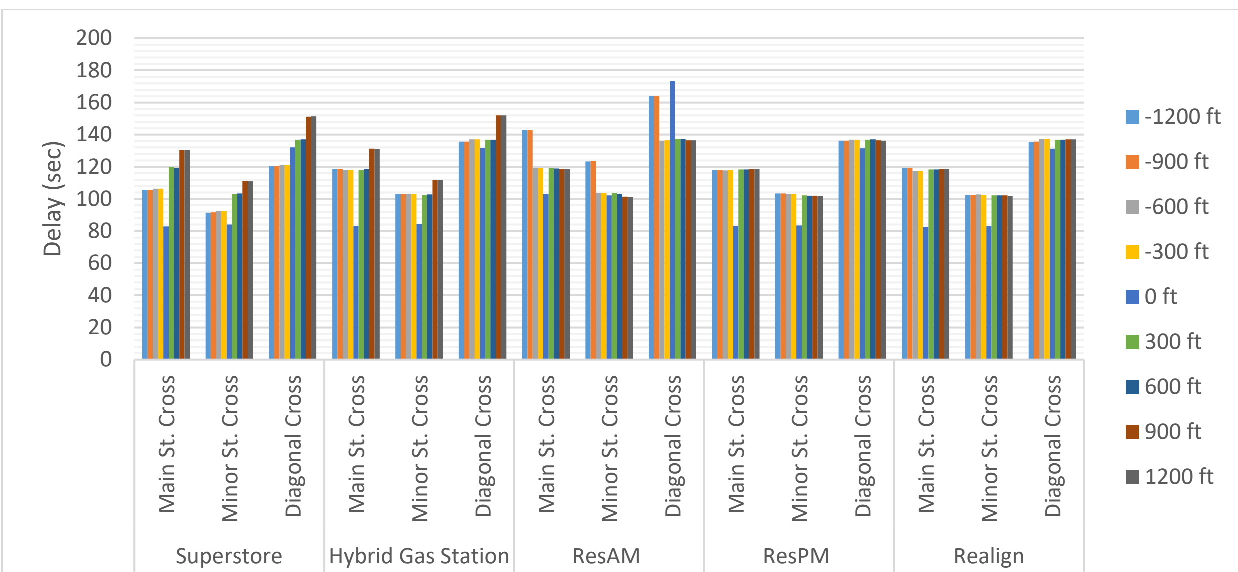
Figure 5-14. Comparison of Bicycle Delay for Minor Street to Main Street Movements

5.5.2 Pedestrian Delay

Figure 5-20 compares pedestrian delay under two volume-to-capacity ratios for three crossing movements: main street crossing, minor street crossing, and diagonal crossing, respectively. Simulation results indicate that under most of the scenarios, 4-leg standard intersections resulted in a lower pedestrian delay in comparison with offset T-intersections. At a high v/c ratio, for both LR and RL offsets, it was found that a longer spacing tends to result in a higher pedestrian delay. This is likely explained by the differences in the cycle length. For the 4-leg intersection, the cycle lengths varied from 90-110 seconds, whereas for the offset intersections the cycle lengths varied from 110-130 seconds. The offset intersections tend to have longer cycle lengths to achieve vehicular progression and reduce queue lengths, but results in an increased delay for pedestrians.



(a) v/c=0.7



(b) v/c=0.9

Figure 5-20. Comparison of Pedestrian Delay for Various Movements

6. Movement Based SPF

The movement based safety performance function (MBSPF) method developed by Chase et al. (2020) presented a safety performance function (SPF) based on conflict point and non-conflict point crash data and is applicable to various intersection geometries. The MBSPF requires daily turning movement counts as an input. To evaluate the five volume scenarios, the hourly volumes were factored to daily volumes. Cunningham et al. (2016) developed five daily volume profiles, detailing the percent of traffic in each hour for each profile. The average peak hour of the five profiles contained 8.37% of the daily traffic. Therefore, to generate the daily turning movement counts for SPF analysis, each of the five hourly volumes were assumed to be 8.37% of the total daily volumes. The resulting daily counts are presented in Tables 6-1 and 6-2. These volumes were then applied to the LR, RL, and four-leg intersection SPF models.

The predicted crashes are shown in Table 6-3 along with the percentage of crashes related to the standard four-leg intersection. Generally speaking, the LR and RL geometries have a similar number of predicted crashes. These values tend to be 87.7-90.4% of the total predicted number of crashes for the four-leg standard intersection geometry. This reduction in crashes is consistent with existing literature, although some collision studies tend to show an even greater reduction.

Table 6-1. Daily Turning Movement Volume for Three Intersection Layouts (v/c = 0.7)

4-Leg Layout	Daily Turning Movement Volumes (vehicles)											
	NB			SB			EB			WB		
	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT
Hybrid Gas Station (PM)	2,545	346	3,823	2,139	358	1,434	2,127	9,427	2,019	1,350	6,284	1,422
Superstore (PM)	1,744	1,207	2,616	3,202	1,243	2,139	3,154	6,476	1,386	920	4,313	2,103
Residential AM	4,707	227	3,142	538	669	812	179	7,754	1,661	2,485	11,625	263
Residential PM	2,832	753	4,241	526	442	358	908	10,478	2,246	1,493	6,989	597
Realign	1,971	1,649	2,963	1,971	1,099	1,314	1,314	10,526	1,314	872	7,025	872

LR Layout	Left Intersection						Right Intersection					
	SB		EB		WB		NB		EB		WB	
	LT	RT	LT	Thru	Thru	RT	LT	RT	Thru	RT	LT	Thru
Hybrid Gas Station (PM)	2,497	1,434	2,127	11,458	8,829	1,768	2,891	3,823	11,577	2,378	1,350	7,706
Superstore (PM)	4,444	2,139	3,154	7,861	6,057	3,309	2,951	2,616	9,665	2,628	920	6,416
Residential AM	1,207	812	179	9,415	16,332	490	4,922	3,142	8,292	2,330	2,485	11,888
Residential PM	968	358	908	12,724	9,809	1,350	3,584	4,241	11,004	2,688	1,493	7,587
Realign	3,070	1,314	1,314	11,840	8,996	2,521	3,620	2,963	12,509	2,413	872	7,897

RL Layout	Left Intersection						Right Intersection					
	NB		EB		WB		SB		EB		WB	
	LT	RT	RT	Thru	Thru	LT	LT	RT	Thru	LT	RT	Thru
Hybrid Gas Station (PM)	2,545	4,170	11,565	2,019	1,708	7,718	2,139	1,792	2,473	13,250	7,634	1,422
Superstore (PM)	1,744	3,823	9,618	1,386	2,162	6,452	3,202	3,381	4,361	9,092	5,233	2,103
Residential AM	4,707	3,357	7,933	1,661	3,166	12,437	538	1,481	406	10,884	14,110	263
Residential PM	2,832	4,994	11,374	2,246	1,935	7,336	526	800	1,661	14,719	8,483	597
Realign	1,971	4,612	11,840	1,314	1,971	8,339	1,971	2,413	2,963	13,489	7,897	872

Table 6-2. Daily Turning Movement Volume for Three Intersection Layouts (v/c = 0.9)

4-Leg Layout	Daily Turning Movement Volumes (vehicles)											
	NB			SB			EB			WB		
	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT	LT	Thru	RT
Hybrid Gas Station (PM)	3,441	346	5,161	2,139	358	1,434	2,127	12,748	2,736	1,816	8,495	1,422
Superstore (PM)	2,987	1,207	4,492	3,202	1,243	2,139	3,154	11,087	2,378	1,589	7,395	2,103
Residential AM	6,213	227	4,146	538	669	812	179	10,239	2,198	3,286	15,352	263
Residential PM	3,716	753	5,579	526	442	358	908	13,787	2,951	1,971	9,188	597
Realign	2,533	2,115	3,811	2,533	1,410	1,697	1,697	13,536	1,697	1,123	9,020	1,123
LR Layout	**Left Intersection**						**Right Intersection**					
	SB		EB		WB		NB		EB		WB	
	LT	RT	LT	Thru	Thru	RT	LT	RT	Thru	RT	LT	Thru
Hybrid Gas Station (PM)	2,497	1,434	2,127	15,472	11,935	1,768	3,787	5,161	14,886	3,094	1,816	9,916
Superstore (PM)	4,444	2,139	3,154	13,465	10,382	3,309	4,194	4,492	14,289	3,620	1,589	9,486
Residential AM	1,207	812	179	12,437	21,577	490	6,440	4,146	10,777	2,867	3,286	15,627
Residential PM	968	358	908	16,738	12,915	1,350	4,468	5,579	14,313	3,393	1,971	9,797
Realign	3,943	1,697	1,697	15,233	11,565	3,238	4,659	3,811	16,081	3,106	1,123	10,155
RL Layout	**Left Intersection**						**Right Intersection**					
	NB		EB		WB		SB		EB		WB	
	LT	RT	RT	Thru	Thru	LT	LT	RT	Thru	LT	RT	Thru
Hybrid Gas Station (PM)	3,441	5,508	14,875	2,736	2,174	9,928	2,139	1,792	2,473	17,897	10,311	1,422
Superstore (PM)	2,987	5,687	14,241	2,378	2,832	9,522	3,202	3,381	4,361	15,568	8,973	2,103
Residential AM	6,213	4,373	10,418	2,198	3,967	16,165	538	1,481	406	14,385	18,650	263
Residential PM	3,716	6,332	14,695	2,951	2,413	9,546	526	800	1,661	19,367	11,159	597
Realign	2,533	5,926	15,233	1,697	2,533	10,717	2,533	3,106	3,811	17,348	10,155	1,123

Table 6-3. Predicted Number of Crashes Using MBSPF

4-Leg Layout	Predicted Number of Crashes					
	v/c = 0.7			v/c = 0.9		
	LR	4Leg	RL	LR	4Leg	RL
Hybrid Gas Station (PM)	8.85 (89.7%)	9.87	8.80 (89.2%)	11.69 (90.4%)	12.93	11.64 (90.0%)
Superstore (PM)	8.02 (89.3%)	8.98	7.99 (89.0%)	12.12 (90.4%)	13.40	12.06 (90.0%)
Residential AM	9.05 (88.8%)	10.19	8.96 (87.9%)	12.23 (89.9%)	13.61	12.12 (89.1%)
Residential PM	8.27 (88.4%)	9.36	8.25 (88.1%)	11.03 (89.5%)	12.33	11.00 (89.2%)
Realign	8.85 (88.5%)	10.00	8.77 (87.7%)	11.94 (89.5%)	13.34	11.85 (88.8%)

7. Conclusions and Recommendations

When desiring to expand an existing three-leg intersection, a fourth leg can be added to create a standard 4-leg standard intersection, or the fourth leg can be shifted up- or downstream to create an offset T-intersection. Existing literature regarding the safety of such a decision suggests the offset T-intersection results in as much as a 50% reduction in crashes over the four-leg intersection, which is mainly due to the reduction in conflict points for the offset design.

Nevertheless, there is less existing literature on the operational differences between 4-leg standard and offset T-intersections. This research effort employed a microsimulation approach to investigate the differences in operational performance between 4-leg standard intersections and offset T-intersections under various volumes, spacings, OD patterns, and signal timing schemes. Based on the simulation results, this report provides NCDOT recommendations for the selection of the optimal offset T-intersection configuration for each specific development project.

Specific recommendation for each development scenario is presented as follows:

Superstore Development Scenario

- This research recommends a LR offset T-intersection with a stem spacing longer than 600 ft. for the Superstore development scenario.

Hybrid Gas Station Development Scenario

- This research recommends a LR offset T-intersection for the hybrid gas station development scenario; when possible, a spacing that is longer than 300 ft. is recommended.

Residential Area Development Scenario

- This research recommends that under a relatively low v/c ratio condition, a LR offset T-intersection with a medium spacing (e.g., around 600 ft.) for both AM and PM periods. When the v/c ratio is high, a LR offset T-intersection with a longer spacing (e.g., longer than 600 ft.) is recommended.

Realign Scenario

- This research recommends a LR offset T-intersection with a relatively longer spacing (i.e., longer than 900 ft.) for the Realign scenario, particularly when v/c ratio is larger than 0.7.

Specific findings for each of the performance metrics from this research are listed as follows:

Queue Length

Average Through Movement Queue Length divided by Spacing

This research effort revealed that for both v/c levels, RL offsets are generally superior to LR offsets in terms of avoiding main street through movements from queuing at signals. For the LR offset T-intersection, queue length to spacing ratio decreases with the increase of spacing; while for RL offset T-intersection, queue length to spacing ratio tends to be impacted by both spacing and development category.

Maximum Left-Turn Movement Queue Length divided by Storage

This research reveals that for RL offset T-intersection, usually it requires a relatively longer stem spacing (e.g., > 900 ft) to prevent queue spillback, even if under a low v/c level.

Delay

Vehicle Delay

Main Street to Main Street

This research found that under about half of the scenarios, offset T-intersections are superior to 4-leg intersection in terms of reducing delay for the main street through movements. For the LR offset, a longer spacing generally resulted in a lower vehicle delay; while for the RL offset a shorter spacing generally resulted in a lower delay.

Minor Street to Minor Street

Simulation results showed that the 4-leg standard intersection had the lowest minor street through movement delay for all the scenarios. For the LR offset, delay decreased with increased spacing and for RL offset, delay increased with increased spacing.

Main Street to Minor Street

Simulation results showed that the performance of main street left turn and right turn movements tend to be impacted by development type. In general, right-turn movements have lower delays than left-turn movements. In addition, it was found that for the EBL movement, the LR offset generally outperforms RL offset.

Minor Street to Main Street

This research found that minor street right turns have lower delays than left turns. For right turn movements, the LR offset-T tends to be superior to RL offset; while for left-turn movements, generally the RL offset is superior to LR offset. For the RL offset, a shorter stem spacing is superior to a longer spacing.

Bicycle Delay

This research found that bicycle delay has a similar trend as vehicle delay. Specifically, for main street through movements, the LR offset outperforms RL offset. Bicycle delay decreases with an increased LR offset spacing (or decreased RL offset spacing). For the minor street through movement, bicycle delay tends to be affected by development type. For main street left turn and right turn movements, this research found that under most scenarios, offset T-intersections are superior to 4-leg standard intersections and the LR offset is superior to the RL offset. For the LR offset, a shorter stem spacing tends to reduce bicycle delay, while for RL offset, a longer stem spacing will reduce bicycle delay. For minor street left turn and right turn movements, simulation results revealed that 4-Leg standard intersections result in the highest bicycle delay, particularly under high v/c scenarios.

Pedestrian Delay

This research found that under most of the scenarios, 4-leg standard intersections resulted in a lower pedestrian delay in comparison with offset T-intersections. For both LR and RL offsets, it was found that a longer spacing tends to result in a higher pedestrian delay.

This research did not take into account travel time as a performance measure, which is mainly because travel time is dependent upon site conditions such as the spacing between two intersections. Therefore, future work needs to analyze the distance traveled under each spacing level for realignment projects. Additionally, this research did not consider a RL geometry with left turn lanes which each extended the full distance between the stems, instead focusing on a geometry in which the combined length of the left turn lanes was equal to the distance between the stems. This allowed equivalent use of right-of-way to be considered in both RL and LR scenarios. It should be noted that, should additional right-of-way be available, extended left turn lanes may improve queue storage concerns making this is a viable intersection configuration under many scenarios.

It is necessary to point out that this research presented comparisons of the effects of spacing on traffic operation under four hypothetical development scenarios; accordingly, it provided NCDOT engineers with practical planning-level recommendations for each development scenario. As this research focused only on signalized offset T-intersections with a specific number of lanes, future research needs to cover a wider range of offsets and number of lanes, and develop an optimal signal timing scheme based on field collected traffic flow data to improve the operation of the offset T-intersection.

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9. Appendices

Appendix A. ITE Vehicle Trip Generation

The ITE trip generation rates for each development scenario are presented in Table A-1. Based on these trip generation rates, the inbound, outbound as well as the pass by traffic were estimated, as shown in Table A-2. Then, the research team determined the percentage of the generated traffic for each direction and assigned the generated trips to each link (Table A-3). Finally, the traffic volumes used for microsimulation modeling were calculated, as listed in Table A-4 (v/c = 0.7) and Table A-5 (v/c = 0.9).

Table A-1: ITE Trip Generation Rates used by this research

Residential

Description/ITE Code	Units	ITE Vehicle Trip Generation Rates (peak hours are for peak hour of adjacent street traffic unless highlighted)								Expected Units	Total Generated Trips			Total Distribution of Generated Trips					
		Weekday	AM	PM	Pass-By	AM In	AM Out	PM In	PM Out		Daily	AM Hour	PM Hour	AM In	AM Out	Pass-By	PM In	PM Out	Pass-By
Single Family Homes 210	DU	9.52	0.75	1.00		25%	75%	63%	37%		0	0	0	0	0	0	0	0	0
Single Family Homes 210	DU	9.52	0.75	1.00		25%	75%	63%	37%	300.0	2,856	225	300	56	169	0	189	111	0

Target

Description/ITE Code	Units	ITE Vehicle Trip Generation Rates (peak hours are for peak hour of adjacent street traffic unless highlighted)								Expected Units	Total Generated Trips			Total Distribution of Generated Trips					
		Weekday	AM	PM	Pass-By	AM In	AM Out	PM In	PM Out		Daily	AM Hour	PM Hour	AM In	AM Out	Pass-By	PM In	PM Out	Pass-By
Free Standing Discount Superstore 81:	KSF^2	50.75	1.85	4.35	28%	56%	44%	49%	51%		0	0	0	0	0	0	0	0	0
Free Standing Discount Superstore 81:	KSF^2	50.75	1.85	4.35	28%	56%	44%	49%	51%	130.0	6,598	241	566	97	76	67	200	208	158

Sheetz

Description/ITE Code	Units	ITE Vehicle Trip Generation Rates (peak hours are for peak hour of adjacent street traffic unless highlighted)								Expected Units	Total Generated Trips			Total Distribution of Generated Trips					
		Weekday	AM	PM	Pass-By	AM In	AM Out	PM In	PM Out		Daily	AM Hour	PM Hour	AM In	AM Out	Pass-By	PM In	PM Out	Pass-By
Shopping Center 820 (Equation)	KSF^2	Equations			34%	62%	38%	48%	52%		0	0	0	0	0	0	0	0	0
Convenience. Mkt w/ Gas Pumps 853	Fuel Position	542.60	16.57	19.07	66%	50%	50%	50%	50%		0	0	0	0	0	0	0	0	0
Shopping Center 820 (Equation)	KSF^2	Equations			34%	62%	38%	48%	52%	8.0	1,315	33	110	14	8	11	35	38	38
Convenience. Mkt w/ Gas Pumps 853	Fuel Position	542.60	16.57	19.07	66%	50%	50%	50%	50%	16.0	8,682	265	305	45	45	175	52	52	201

Table A-2: Generated trips for each development scenario

	Inbound	Outbound	Passby
Hybrid Gas Station (PM)	87	90	239
Superstore (PM)	302	312	238
Residential AM	56	169	0
Residential PM	189	111	0
Realign	0	0	0

Table A-3: Assignment of the generated trips to each link

	AM	PM	5th
% EB on Main Rd	0.4	0.6	0.6
Major vol / Stem Vol	2	2	2
Major vol / (Stem + Maj)	0.67	0.67	0.67
Turn %	0.15	0.15	**0.10**

Table A-4: Estimated turning traffic volume for each development (v/c = 0.7)

Volumes	Turning Movement Volumes											
	NB			SB			EB			WB		
	L	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Hybrid Gas Station (PM)	213	29	320	179	30	120	178	789	169	113	526	119
Superstore (PM)	146	101	219	268	104	179	264	542	116	77	361	176
Residential AM	**394**	19	263	45	56	68	15	649	139	208	973	22
Residential PM	237	63	355	44	37	30	76	877	188	125	585	50
Realign	165	138	248	165	92	110	110	**881**	110	73	588	73

Table A-5: Estimated turning traffic volume for each development (v/c = 0.9)

Volumes	Turning Movement Volumes											
	NB			SB			EB			WB		
	L	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**	**L**	**T**	**R**
Hybrid Gas Station (PM)	288	29	432	179	30	120	178	1067	229	152	711	119
Superstore (PM)	250	101	376	268	104	179	264	928	199	133	619	176
Residential AM	**520**	19	347	45	56	68	15	857	184	275	1285	22
Residential PM	311	63	467	44	37	30	76	1154	247	165	769	50
Realign	212	177	319	212	118	142	142	**1133**	142	94	755	94

Appendix B. VISSIM Vehicle Inputs

Appendix-B1. VISSIM Vehicle Inputs

v/c Ratio	Intersection Approach	Traffic Volume Input (vph) for each OD pattern				
		Hybrid Gas Station	Superstore	ResAM	ResPM	Realign
0.7	NB	562	466	675	655	551
	SB	329	550	169	111	367
	EB	1137	921	803	1140	1102
	WB	758	614	1204	760	734
0.9	NB	748	727	886	841	708
	SB	329	550	169	111	472
	EB	1473	1390	1056	1477	1416
	WB	982	927	1583	985	944

Appendix-B2. VISSIM Vehicle Static Routes – Relative Flow (Turning Volume)

v/c Ratio	Approach	Movement	Relative Flow for each OD pattern				
			Hybrid Gas Station	Superstore	ResAM	ResPM	Realign
0.7	NB	Left	0.379	0.314	0.583	0.362	0.300
		Thru	0.052	0.216	0.028	0.096	0.250
		Right	0.569	0.470	0.389	0.542	0.450
	SB	Left	0.545	0.487	0.267	0.400	0.450
		Thru	0.091	0.189	0.333	0.333	0.250
		Right	0.364	0.324	0.400	0.267	0.300
	EB	Left	0.157	0.286	0.019	0.066	0.100
		Thru	0.694	0.588	0.808	0.769	0.800
		Right	0.149	0.126	0.173	0.165	0.100
	WB	Left	0.149	0.126	0.173	0.165	0.100
		Thru	0.694	0.588	0.808	0.769	0.800
		Right	0.157	0.286	0.019	0.066	0.100
0.9	NB	Left	0.385	0.345	0.587	0.370	0.300
		Thru	0.039	0.139	0.021	0.075	0.250
		Right	0.577	0.517	0.392	0.555	0.450
	SB	Left	0.545	0.487	0.267	0.400	0.450
		Thru	0.091	0.189	0.333	0.333	0.250
		Right	0.364	0.324	0.400	0.267	0.300
	EB	Left	0.121	0.190	0.014	0.051	0.100
		Thru	0.724	0.667	0.812	0.781	0.800
		Right	0.155	0.143	0.174	0.167	0.100
	WB	Left	0.155	0.143	0.174	0.167	0.100
		Thru	0.724	0.667	0.812	0.781	0.800
		Right	0.121	0.190	0.014	0.051	0.100

Appendix C. Signal Timing Plans

Appendix-C1. Signal timing plans for offset T-intersections tested in VISSIM microsimulation

v/c	OD Pattern	Spacing and Signal	Green Time Split (s)										Cycle Length (s)
			1	2	22	3	4	5	6	26	7	8	
0.7	Superstore	+300_T3Lag	23	32	94	35	62	30	25	55	35	27	90
		+900_4CSplit	9	35	9	32	9	16	28	9	44	9	120
		-300_3Lag	30	25	41	35	9	23	32	30	35	9	90
		-900_3Lead	30	25	41	35	9	23	32	30	35	9	90
	Hybrid Gas Station	+300_T3Lag	23	32	94	35	9	30	25	37	35	9	90
		+900_4CSplit	9	32	32	32	9	9	32	9	37	9	110
		-300_3Lag	10	35	32	35	9	13	32	25	35	9	80
		-900_3Lead	27	28	32	35	9	19	36	25	35	9	90
	ResAM	+300_T3Lag	43	32	92	35	9	50	25	114	35	9	110
		+900_4CSplit	9	32	9	32	9	9	32	13	37	9	110
		-300_3Lag	20	45	32	35	9	33	32	55	35	9	100
		-900_LRSplit	32	25	40	36	9	23	34	55	37	9	130
	ResPM	+300_T3Lag	18	47	104	35	9	40	25	26	35	27	100
		+900_4CSplit	9	32	88	32	9	9	32	11	37	9	110
		-300_3Lag	16	49	32	35	9	24	41	25	35	9	100
		-900_3Lead	129	25	145	36	194	122	32	75	36	9	190
	Realign	+300_T3Lag	29	36	104	35	9	40	25	45	35	16	100
		+900_4CSplit	9	32	21	32	9	10	31	9	37	32	110
		-300_3Lag	34	31	38	35	9	15	50	31	35	9	100
		-900_3Lead	30	25	33	35	9	15	40	27	35	9	90
0.9	Superstore	+300_T3Lag	37	38	114	35	15	49	26	46	35	22	110
		+900_4CSplit	10	32	9	32	9	9	33	9	46	9	120
		-300_3Lag	40	25	44	35	9	33	32	30	35	9	100
		-900_3Lead	40	25	44	35	9	27	38	30	35	9	100
	Hybrid Gas Station	+300_T3Lag	23	52	114	35	9	50	25	36	35	23	110
		+900_4CSplit	9	36	34	33	9	13	32	9	42	9	120
		-300_3Lag	31	44	35	35	9	43	32	28	35	9	110
		-900_3Lead	28	47	35	35	9	43	32	28	35	9	110
	ResAM	+300_T3Lag	39	36	95	35	9	50	25	114	35	9	110
		+900_4CSplit	9	32	12	32	9	9	32	16	37	9	110
		-300_3Lag	54	31	35	35	9	53	32	83	35	9	110
		-900_LRSplit	32	25	38	37	10	9	48	39	36	9	130
	ResPM	+300_T3Lag	20	55	114	35	9	50	25	25	35	31	110
		+900_4CSplit	9	32	96	32	9	9	32	14	37	9	110
		-300_3Lag	19	56	35	35	9	41	34	26	35	9	110
		-900_3Lead	19	56	35	35	9	41	34	26	35	9	110
	Realign	+300_T3Lag	22	53	114	35	10	38	37	47	35	32	110
		+900_4CSplit	10	32	18	32	9	9	33	9	36	9	110
		-300_3Lag	48	25	52	37	9	25	48	35	37	9	110
		-900_3Lead	30	45	35	35	9	43	32	33	35	9	110

Appendix-C2. Signal timing plans for 4-leg intersection tested in VISSIM microsimulation

v/c	OD Pattern	Spacing and Signal	Green Time Split (s)								Cycle Length (s)
			1	2	3	4	5	6	7	8	
0.7	Superstore	+000_4C	18	31	16	35	25	24	20	31	100
	Hybrid Gas Station	+000_4C	13	31	15	31	20	24	15	31	90
	ResAM	+000_4C	17	31	21	31	13	35	21	31	100
	ResPM	+000_4C	12	31	16	31	19	24	16	31	90
	Realign	+000_4C	14	31	14	31	19	26	14	31	90
0.9	Superstore	+000_4C	11	31	17	31	18	24	17	31	90
	Hybrid Gas Station	+000_4C	13	31	15	31	20	24	15	31	90
	ResAM	+000_4C	22	31	23	34	9	44	26	31	110
	ResPM	+000_4C	14	31	14	31	15	30	12	33	90
	Realign	+000_4C	12	31	16	31	15	28	16	31	90

Appendix D. Simulation Scenarios

Model #	v/c	Volume	Spacing	Signal Timing	File Name
1	0.7	Superstore	-1200	3Lead	1_Tgt_0.7_-1200_3Lead
2	0.7	Superstore	-900	3Lead	2_Tgt_0.7_-900_3Lead
3	0.7	Superstore	-600	3Lag	3_Tgt_0.7_-600_3Lag
4	0.7	Superstore	-300	3Lag	4_Tgt_0.7_-300_3Lag
5	0.7	Superstore	0	4C	5_Tgt_0.7_0_4C
6	0.7	Superstore	300	T3Lag	6_Tgt_0.7_300_T3Lag
7	0.7	Superstore	600	T3Lag	7_Tgt_0.7_600_T3Lag
8	0.7	Superstore	900	4CSplit	8_Tgt_0.7_900_4CSplit
9	0.7	Superstore	1200	4CSplit	9_Tgt_0.7_1200_4CSplit
10	0.7	Hybrid Gas Station	-1200	3Lead	10_Shz_0.7_-1200_3Lead
11	0.7	Hybrid Gas Station	-900	3Lead	11_Shz_0.7_-900_3Lead
12	0.7	Hybrid Gas Station	-600	3Lag	12_Shz_0.7_-600_3Lag
13	0.7	Hybrid Gas Station	-300	3Lag	13_Shz_0.7_-300_3Lag
14	0.7	Hybrid Gas Station	0	4C	14_Shz_0.7_0_4C
15	0.7	Hybrid Gas Station	300	T3Lag	15_Shz_0.7_300_T3Lag
16	0.7	Hybrid Gas Station	600	T3Lag	16_Shz_0.7_600_T3Lag
17	0.7	Hybrid Gas Station	900	4CSplit	17_Shz_0.7_900_4CSplit
18	0.7	Hybrid Gas Station	1200	4CSplit	18_Shz_0.7_1200_4CSplit
19	0.7	ResAM	-1200	LRSplit	19_ResAM_0.7_-1200_LRSplit
20	0.7	ResAM	-900	LRSplit	20_ResAM_0.7_-900_LRSplit
21	0.7	ResAM	-600	3Lag	21_ResAM_0.7_-600_3Lag
22	0.7	ResAM	-300	3Lag	22_ResAM_0.7_-300_3Lag
23	0.7	ResAM	0	4C	23_ResAM_0.7_0_4C
24	0.7	ResAM	300	T3Lag	24_ResAM_0.7_300_T3Lag
25	0.7	ResAM	600	T3Lag	25_ResAM_0.7_600_T3Lag
26	0.7	ResAM	900	4CSplit	26_ResAM_0.7_900_4CSplit
27	0.7	ResAM	1200	4CSplit	27_ResAM_0.7_1200_4CSplit
28	0.7	ResPM	-1200	3Lead	28_ResPM_0.7_-1200_3Lead
29	0.7	ResPM	-900	3Lead	29_ResPM_0.7_-900_3Lead
30	0.7	ResPM	-600	3Lag	30_ResPM_0.7_-600_3Lag
31	0.7	ResPM	-300	3Lag	31_ResPM_0.7_-300_3Lag
32	0.7	ResPM	0	4C	32_ResPM_0.7_0_4C
33	0.7	ResPM	300	T3Lag	33_ResPM_0.7_300_T3Lag
34	0.7	ResPM	600	T3Lag	34_ResPM_0.7_600_T3Lag
35	0.7	ResPM	900	4CSplit	35_ResPM_0.7_900_4CSplit
36	0.7	ResPM	1200	4CSplit	36_ResPM_0.7_1200_4CSplit
37	0.7	Realign	-1200	3Lead	37_Realign_0.7_-1200_3Lead

Model #	v/c	Volume	Spacing	Signal Timing	File Name
38	0.7	Realign	-900	3Lead	38_Realign_0.7_-900_3Lead
39	0.7	Realign	-600	3Lag	39_Realign_0.7_-600_3Lag
40	0.7	Realign	-300	3Lag	40_Realign_0.7_-300_3Lag
41	0.7	Realign	0	4C	41_Realign_0.7_0_4C
42	0.7	Realign	300	T3Lag	42_Realign_0.7_300_T3Lag
43	0.7	Realign	600	T3Lag	43_Realign_0.7_600_T3Lag
44	0.7	Realign	900	4CSplit	44_Realign_0.7_900_4CSplit
45	0.7	Realign	1200	4CSplit	45_Realign_0.7_1200_4CSplit
46	0.9	Superstore	-1200	3Lead	46_Tgt_0.9_-1200_3Lead
47	0.9	Superstore	-900	3Lead	47_Tgt_0.9_-900_3Lead
48	0.9	Superstore	-600	3Lag	48_Tgt_0.9_-600_3Lag
49	0.9	Superstore	-300	3Lag	49_Tgt_0.9_-300_3Lag
50	0.9	Superstore	0	4C	50_Tgt_0.9_0_4C
51	0.9	Superstore	300	T3Lag	51_Tgt_0.9_300_T3Lag
52	0.9	Superstore	600	T3Lag	52_Tgt_0.9_600_T3Lag
53	0.9	Superstore	900	4CSplit	53_Tgt_0.9_900_4CSplit
54	0.9	Superstore	1200	4CSplit	54_Tgt_0.9_1200_4CSplit
55	0.9	Hybrid Gas Station	-1200	3Lead	55_Shz_0.9_-1200_3Lead
56	0.9	Hybrid Gas Station	-900	3Lead	56_Shz_0.9_-900_3Lead
57	0.9	Hybrid Gas Station	-600	3Lag	57_Shz_0.9_-600_3Lag
58	0.9	Hybrid Gas Station	-300	3Lag	58_Shz_0.9_-300_3Lag
59	0.9	Hybrid Gas Station	0	4C	59_Shz_0.9_0_4C
60	0.9	Hybrid Gas Station	300	T3Lag	60_Shz_0.9_300_T3Lag
61	0.9	Hybrid Gas Station	600	T3Lag	61_Shz_0.9_600_T3Lag
62	0.9	Hybrid Gas Station	900	4CSplit	62_Shz_0.9_900_4CSplit
63	0.9	Hybrid Gas Station	1200	4CSplit	63_Shz_0.9_1200_4CSplit
64	0.9	ResAM	-1200	LRSplit	64_ResAM_0.9_-1200_LRSplit
65	0.9	ResAM	-900	LRSplit	65_ResAM_0.9_-900_LRSplit
66	0.9	ResAM	-600	3Lag	66_ResAM_0.9_-600_3Lag
67	0.9	ResAM	-300	3Lag	67_ResAM_0.9_-300_3Lag
68	0.9	ResAM	0	4C	68_ResAM_0.9_0_4C
69	0.9	ResAM	300	T3Lag	69_ResAM_0.9_300_T3Lag
70	0.9	ResAM	600	T3Lag	70_ResAM_0.9_600_T3Lag
71	0.9	ResAM	900	4CSplit	71_ResAM_0.9_900_4CSplit
72	0.9	ResAM	1200	4CSplit	72_ResAM_0.9_1200_4CSplit
73	0.9	ResPM	-1200	3Lead	73_ResPM_0.9_-1200_3Lead
74	0.9	ResPM	-900	3Lead	74_ResPM_0.9_-900_3Lead
75	0.9	ResPM	-600	3Lag	75_ResPM_0.9_-600_3Lag
76	0.9	ResPM	-300	3Lag	76_ResPM_0.9_-300_3Lag

Model #	v/c	Volume	Spacing	Signal Timing	File Name
77	0.9	ResPM	0	4C	77_ResPM_0.9_0_4C
78	0.9	ResPM	300	T3Lag	78_ResPM_0.9_300_T3Lag
79	0.9	ResPM	600	T3Lag	79_ResPM_0.9_600_T3Lag
80	0.9	ResPM	900	4CSplit	80_ResPM_0.9_900_4CSplit
81	0.9	ResPM	1200	4CSplit	81_ResPM_0.9_1200_4CSplit
82	0.9	Realign	-1200	3Lead	82_Realign_0.9_-1200_3Lead
83	0.9	Realign	-900	3Lead	83_Realign_0.9_-900_3Lead
84	0.9	Realign	-600	3Lag	84_Realign_0.9_-600_3Lag
85	0.9	Realign	-300	3Lag	85_Realign_0.9_-300_3Lag
86	0.9	Realign	0	4C	86_Realign_0.9_0_4C
87	0.9	Realign	300	T3Lag	87_Realign_0.9_300_T3Lag
88	0.9	Realign	600	T3Lag	88_Realign_0.9_600_T3Lag
89	0.9	Realign	900	4CSplit	89_Realign_0.9_900_4CSplit
90	0.9	Realign	1200	4CSplit	90_Realign_0.9_1200_4CSplit

Appendix E. Queue Length Simulation Results

Table E1: v/c = 0.7; OD Pattern: Superstore									
Movement	Simulated Queue Length (ft) for each Spacing Level								
	-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
NBL	18.3	18.3	20.4	21.9	23.7	12.1	12.1	20.4	20.3
NBT	18.3	18.3	20.4	21.9	18.2	12.1	12.1	20.4	20.3
NBR	1.2	1.1	0.9	0.9	18.2	2.8	2.2	2.3	2.2
SBL	72.0	72.2	74.8	77.5	147.1	35.8	35.7	68.1	68.2
SBT	72.0	72.2	74.8	77.5	28.8	35.8	35.7	68.1	68.2
SBR	1.2	1.2	1.1	1.2	28.8	2.2	2.2	2.9	2.8
EBL	63.4	63.4	60.5	60.3	81.2	79.9	92.5	114.2	106.7
EBT	16.8	16.8	17.2	17.6	46.6	58.6	52.3	80.9	80.0
EBR	0.7	0.8	1.7	1.3	46.6	0.6	0.7	0.7	0.7
WBL	15.4	15.4	10.3	10.3	17.8	27.6	25.2	17.2	15.8
WBT	13.0	13.0	13.6	14.2	47.8	32.3	31.4	35.6	35.3
WBR	5.7	6.4	4.9	4.1	47.8	3.5	3.3	3.6	3.6
Movement	Queue Length divided by Spacing								
EBTS	1.8%	2.3%	6.2%	12.0%	0.0%	2.2%	1.1%	1.0%	1.0%
WBTS	1.6%	2.3%	3.4%	7.5%	0.0%	0.9%	0.4%	0.1%	0.1%
Movement	Maximum Queue Length divided by Storage								
EBL	n/a	n/a	n/a	n/a	n/a	278%	153%	94%	70%
WBL	n/a	n/a	n/a	n/a	n/a	146%	70%	46%	33%

Table E2: v/c = 0.7; OD Pattern: Hybrid Gas Station									
Movement	**Simulated Queue Length (ft) for each Spacing Level**								
	-1200 (3Lead)	**-900 (3Lead)**	**-600 (3Lag)**	**-300 (3Lag)**	**0 (4C)**	**+300 (T3Lag)**	**+600 (T3Lag)**	**+900 (4CSplit)**	**+1200 (4CSplit)**
NBL	18.4	18.4	15.0	15.2	28.4	16.8	16.9	24.8	24.8
NBT	18.4	18.4	15.0	15.2	7.9	16.8	16.9	24.8	24.8
NBR	2.1	2.1	1.9	2.1	7.9	2.5	2.3	2.1	2.1
SBL	26.2	26.1	20.0	20.1	59.4	21.8	21.8	32.0	32.0
SBT	26.2	26.1	20.0	20.1	6.4	21.8	21.8	32.0	32.0
SBR	0.9	0.9	0.7	0.8	6.4	0.8	0.8	0.9	0.9
EBL	39.6	39.7	57.4	57.7	38.1	19.8	16.6	52.0	46.7
EBT	24.9	24.9	29.2	30.1	78.7	59.7	58.4	122.4	118.2
EBR	0.7	0.6	2.2	1.7	78.7	1.0	1.0	2.0	2.0
WBL	22.1	22.1	34.4	34.0	27.3	16.1	13.0	4.3	2.6
WBT	15.7	15.7	18.3	18.8	50.8	45.4	44.9	50.4	50.4
WBR	0.3	0.3	1.0	0.8	50.8	0.9	0.9	0.8	0.8
Movement	**Queue Length divided by Spacing**								
EBTS	2.5%	3.2%	4.9%	8.8%	0.0%	3.1%	1.7%	2.6%	3.0%
WBTS	2.2%	3.0%	4.2%	8.9%	0.0%	0.5%	0.2%	0.0%	0.0%
Movement	**Maximum Queue Length divided by Storage**								
EBL	n/a	n/a	n/a	n/a	n/a	166%	68%	56%	41%
WBL	n/a	n/a	n/a	n/a	n/a	112%	56%	30%	18%

Table E3: v/c = 0.7; OD Pattern: ResAM									
Movement	Simulated Queue Length (ft) for each Spacing Level								
	-1200 (LRSplit)	-900 (LRSplit)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
NBL	61.0	61.0	37.6	39.2	51.8	41.5	41.5	43.3	43.3
NBT	61.0	61.0	37.6	39.2	4.9	41.5	41.5	43.3	43.3
NBR	1.4	1.3	1.3	1.3	4.9	1.2	1.3	0.9	0.9
SBL	22.1	22.1	13.9	13.9	10.0	6.7	6.6	7.1	7.1
SBT	22.1	22.1	13.9	13.9	10.7	6.7	6.6	7.1	7.1
SBR	0.6	0.6	0.5	0.5	10.7	1.5	1.3	1.2	1.2
EBL	4.3	4.3	2.2	2.2	3.4	3.5	3.3	5.3	5.0
EBT	13.9	13.9	18.4	19.0	74.9	41.5	41.4	67.4	66.2
EBR	1.4	1.5	0.9	1.1	74.9	1.4	1.5	1.5	1.5
WBL	52.1	52.2	58.5	58.6	73.2	49.4	43.2	7.7	5.8
WBT	16.2	16.2	23.5	24.7	59.0	80.7	76.9	117.8	118.8
WBR	0.0	0.0	0.0	0.0	59.0	0.0	0.0	0.1	0.1
Movement	Queue Length divided by Spacing								
EBTS	1.4%	2.1%	4.3%	7.8%	0.0%	1.6%	0.8%	1.4%	1.6%
WBTS	1.6%	2.1%	8.0%	18.3%	0.0%	0.8%	0.6%	0.0%	0.0%
Movement	Maximum Queue Length divided by Storage								
EBL	n/a	n/a	n/a	n/a	n/a	43%	21%	16%	11%
WBL	n/a	n/a	n/a	n/a	n/a	242%	100%	41%	24%

Table E4: v/c = 0.7; OD Pattern: ResPM									
Movement	**Simulated Queue Length (ft) for each Spacing Level**								
	-1200 (3Lead)	**-900 (3Lead)**	**-600 (3Lag)**	**-300 (3Lag)**	**0 (4C)**	**+300 (T3Lag)**	**+600 (T3Lag)**	**+900 (4CSplit)**	**+1200 (4CSplit)**
NBL	72.1	72.3	27.9	28.9	30.8	22.1	22.1	27.0	27.0
NBT	72.1	72.3	27.9	28.9	11.0	22.1	22.1	27.0	27.0
NBR	3.4	3.3	2.6	2.9	11.0	4.2	4.1	3.4	3.4
SBL	32.8	32.8	10.9	10.9	9.2	5.4	5.3	6.3	6.3
SBT	32.8	32.8	10.9	10.9	4.5	5.4	5.3	6.3	6.3
SBR	0.2	0.2	0.2	0.1	4.5	0.2	0.2	0.3	0.3
EBL	36.1	36.1	13.1	13.1	15.0	11.1	11.1	26.4	24.3
EBT	13.5	13.5	27.0	27.8	112.3	49.8	49.7	116.1	111.9
EBR	1.5	1.7	1.2	1.4	112.3	1.3	1.2	3.3	2.9
WBL	58.3	58.4	31.2	31.2	32.9	30.8	27.5	5.1	3.3
WBT	7.6	7.6	14.1	14.3	40.5	71.3	69.2	58.3	58.0
WBR	1.1	1.5	0.3	0.2	40.5	0.2	0.2	0.2	0.2
Movement	**Queue Length divided by Spacing**								
EBTS	1.7%	2.3%	4.5%	7.9%	0.0%	2.9%	1.6%	2.8%	3.2%
WBTS	1.7%	2.5%	5.0%	11.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Movement	**Maximum Queue Length divided by Storage**								
EBL	n/a	n/a	n/a	n/a	n/a	96%	44%	38%	28%
WBL	n/a	n/a	n/a	n/a	n/a	138%	67%	34%	21%

Table E5: v/c = 0.7; OD Pattern: Realign									
Movement	**Simulated Queue Length (ft) for each Spacing Level**								
	-1200 (3Lead)	**-900 (3Lead)**	**-600 (3Lag)**	**-300 (3Lag)**	**0 (4C)**	**+300 (T3Lag)**	**+600 (T3Lag)**	**+900 (4CSplit)**	**+1200 (4CSplit)**
NBL	22.2	22.2	35.0	32.8	22.8	16.2	16.3	19.3	19.3
NBT	22.2	22.2	35.0	32.8	20.1	16.2	16.3	19.3	19.3
NBR	1.5	1.5	1.4	1.3	20.1	5.1	4.6	3.6	3.5
SBL	35.3	35.5	58.2	48.8	59.3	25.3	25.3	29.2	29.2
SBT	35.3	35.5	58.2	48.8	16.5	25.3	25.3	29.2	29.2
SBR	0.7	0.7	0.8	0.7	16.5	1.5	1.4	1.6	1.6
EBL	24.2	24.2	32.5	27.1	22.8	42.2	40.1	48.2	45.1
EBT	26.6	26.7	22.0	25.1	72.2	59.9	58.1	125.0	124.2
EBR	0.8	0.9	0.6	1.1	72.2	0.5	0.5	1.0	0.9
WBL	14.4	14.5	11.6	9.9	14.8	28.1	25.8	9.0	8.3
WBT	16.2	16.2	13.4	15.2	44.9	49.9	49.3	55.4	55.3
WBR	3.1	3.8	0.9	1.3	44.9	0.4	0.4	0.4	0.4
Movement	**Queue Length divided by Spacing**								
EBTS	2.4%	2.9%	9.0%	19.3%	0.0%	2.2%	1.1%	2.5%	3.1%
WBTS	1.8%	2.2%	3.4%	7.5%	0.0%	0.4%	0.2%	0.0%	0.0%
Movement	**Maximum Queue Length divided by Storage**								
EBL	n/a	n/a	n/a	n/a	n/a	241%	84%	59%	43%
WBL	n/a	n/a	n/a	n/a	n/a	146%	69%	33%	23%

Table E6: v/c = 0.9; OD Pattern: Superstore									
Movement	Simulated Queue Length (ft) for each Spacing Level								
	-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
NBL	31.6	31.6	33.2	34.8	31.9	27.6	27.5	32.8	32.8
NBT	31.6	31.6	33.2	34.8	19.4	27.6	27.5	32.8	32.8
NBR	3.9	3.8	3.5	3.5	19.4	11.3	8.7	7.9	7.6
SBL	112.0	112.6	120.6	164.4	279.2	55.8	56.3	67.2	67.2
SBT	112.0	112.6	120.6	164.4	27.3	55.8	56.3	67.2	67.2
SBR	1.9	1.9	1.7	1.9	27.3	4.2	4.1	4.3	4.3
EBL	83.8	83.7	77.5	77.4	114.2	78.3	65.2	105.9	98.5
EBT	27.6	27.6	28.5	31.1	185.5	124.8	89.8	218.8	208.8
EBR	2.3	2.6	7.4	6.2	185.5	3.6	3.1	11.0	11.5
WBL	30.3	30.3	20.7	20.7	54.6	49.0	44.4	19.6	17.4
WBT	18.0	18.0	18.6	19.4	89.5	71.2	66.8	66.5	66.3
WBR	5.8	6.8	3.2	3.4	89.5	4.4	4.3	3.4	3.4
Movement	Queue Length divided by Spacing								
EBTS	3.2%	4.3%	13.1%	25.7%	0.0%	3.4%	1.6%	2.7%	2.8%
WBTS	3.0%	4.3%	5.9%	12.8%	0.0%	0.8%	0.3%	0.1%	0.1%
Movement	Maximum Queue Length divided by Storage								
EBL	n/a	n/a	n/a	n/a	n/a	311%	146%	89%	67%
WBL	n/a	n/a	n/a	n/a	n/a	204%	92%	51%	37%

Table E7: v/c = 0.9; OD Pattern: Hybrid Gas Station									
Movement	Simulated Queue Length (ft) for each Spacing Level								
	-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
NBL	33.9	33.9	34.1	35.0	38.2	30.6	30.5	36.8	36.7
NBT	33.9	33.9	34.1	35.0	11.9	30.6	30.5	36.8	36.7
NBR	5.9	5.9	5.8	6.0	11.9	7.8	7.1	6.7	6.6
SBL	40.3	40.3	40.8	41.7	62.5	32.6	32.5	38.1	38.1
SBT	40.3	40.3	40.8	41.7	6.8	32.6	32.5	38.1	38.1
SBR	1.1	1.1	1.1	1.1	6.8	1.0	0.9	1.2	1.2
EBL	50.1	50.0	33.8	33.8	28.9	10.8	8.3	58.0	53.2
EBT	30.0	30.0	32.2	33.8	912.8	78.6	78.1	269.9	251.8
EBR	0.9	0.9	2.6	2.6	912.8	3.0	2.9	20.9	15.3
WBL	39.3	39.3	38.2	38.1	48.5	38.9	34.0	11.7	8.2
WBT	16.9	16.9	17.7	18.4	75.5	131.6	120.8	67.3	67.5
WBR	0.4	0.3	0.6	0.8	75.5	1.7	1.5	0.8	0.8
Movement	Queue Length divided by Spacing								
EBTS	3.5%	4.7%	7.4%	14.1%	0.0%	3.6%	1.9%	3.4%	3.5%
WBTS	3.2%	4.7%	8.8%	19.7%	0.0%	0.4%	0.2%	0.0%	0.0%
Movement	Maximum Queue Length divided by Storage								
EBL	n/a	n/a	n/a	n/a	n/a	136%	55%	56%	43%
WBL	n/a	n/a	n/a	n/a	n/a	171%	77%	45%	30%

Table E8: v/c = 0.9; OD Pattern: ResAM									
Movement	**Simulated Queue Length (ft) for each Spacing Level**								
	-1200 (LRSplit)	**-900 (LRSplit)**	**-600 (3Lag)**	**-300 (3Lag)**	**0 (4C)**	**+300 (T3Lag)**	**+600 (T3Lag)**	**+900 (4CSplit)**	**+1200 (4CSplit)**
NBL	94.3	94.0	63.3	75.1	84.6	56.8	56.9	58.6	58.5
NBT	94.3	94.0	63.3	75.1	7.1	56.8	56.9	58.6	58.5
NBR	2.2	2.2	2.3	2.5	7.1	2.3	2.5	2.0	2.0
SBL	22.1	22.1	16.8	16.8	11.9	6.1	6.1	7.1	7.1
SBT	22.1	22.1	16.8	16.8	13.2	6.1	6.1	7.1	7.1
SBR	0.6	0.7	0.8	0.8	13.2	3.5	2.3	1.7	1.7
EBL	4.7	4.8	2.5	2.5	3.2	2.7	2.7	4.5	4.1
EBT	19.3	19.3	24.4	25.2	482.6	64.6	64.7	99.7	97.7
EBR	3.9	3.9	3.4	3.3	482.6	3.6	3.5	5.4	5.2
WBL	85.0	84.7	68.7	68.5	97.3	78.3	61.8	7.9	6.9
WBT	24.3	24.4	30.8	38.8	92.0	446.7	251.3	966.5	857.9
WBR	0.0	0.0	0.0	0.0	92.0	0.0	0.0	0.1	0.1
Movement	**Queue Length divided by Spacing**								
EBTS	1.8%	3.0%	7.1%	12.9%	0.0%	2.4%	1.1%	2.5%	3.0%
WBTS	2.2%	3.0%	10.3%	24.5%	0.0%	2.5%	1.1%	0.0%	0.0%
Movement	**Maximum Queue Length divided by Storage**								
EBL	n/a	n/a	n/a	n/a	n/a	38%	19%	13%	10%
WBL	n/a	n/a	n/a	n/a	n/a	277%	147%	39%	25%

Table E9: v/c = 0.9; OD Pattern: ResPM									
Movement	**Simulated Queue Length (ft) for each Spacing Level**								
	-1200 (3Lead)	**-900 (3Lead)**	**-600 (3Lag)**	**-300 (3Lag)**	**0 (4C)**	**+300 (T3Lag)**	**+600 (T3Lag)**	**+900 (4CSplit)**	**+1200 (4CSplit)**
NBL	39.7	39.7	40.6	44.6	44.0	32.8	32.9	34.4	34.5
NBT	39.7	39.7	40.6	44.6	14.5	32.8	32.9	34.4	34.5
NBR	6.9	6.7	6.5	7.2	14.5	10.7	10.5	6.9	7.4
SBL	13.3	13.3	12.9	12.9	9.3	6.6	6.6	6.3	6.3
SBT	13.3	13.3	12.9	12.9	4.5	6.6	6.6	6.3	6.3
SBR	0.2	0.2	0.1	0.1	4.5	0.2	0.2	0.3	0.3
EBL	19.5	19.4	9.7	9.6	9.7	10.4	10.6	23.3	21.6
EBT	34.3	34.3	35.8	37.3	1284.3	75.4	75.3	990.7	796.6
EBR	1.7	1.4	3.4	3.4	1284.3	3.7	3.6	516.1	341.2
WBL	49.7	49.7	48.1	47.8	50.2	49.8	47.0	5.5	3.4
WBT	16.8	16.8	17.5	19.1	50.9	264.7	234.0	82.7	82.7
WBR	0.4	0.6	0.3	0.3	50.9	0.4	0.4	0.2	0.1
Movement	**Queue Length divided by Spacing**								
EBTS	2.8%	3.1%	6.7%	11.8%	0.0%	4.0%	2.1%	4.7%	5.7%
WBTS	2.6%	3.5%	12.4%	28.9%	0.0%	0.1%	0.0%	0.0%	0.0%
Movement	**Maximum Queue Length divided by Storage**								
EBL	n/a	n/a	n/a	n/a	n/a	106%	42%	36%	26%
WBL	n/a	n/a	n/a	n/a	n/a	182%	87%	36%	21%

Table E10: v/c = 0.9; OD Pattern: Realign									
Movement	**Simulated Queue Length (ft) for each Spacing Level**								
	-1200 (3Lead)	**-900 (3Lead)**	**-600 (3Lag)**	**-300 (3Lag)**	**0 (4C)**	**+300 (T3Lag)**	**+600 (T3Lag)**	**+900 (4CSplit)**	**+1200 (4CSplit)**
NBL	41.7	41.7	44.3	50.2	27.9	22.7	22.7	24.1	24.1
NBT	41.7	41.7	44.3	50.2	28.1	22.7	22.7	24.1	24.1
NBR	3.4	3.4	3.1	2.8	28.1	16.4	12.9	7.2	7.0
SBL	106.1	107.4	296.3	743.4	90.7	40.7	40.6	40.0	40.1
SBT	106.1	107.4	296.3	743.4	23.8	40.7	40.6	40.0	40.1
SBR	1.5	1.5	1.3	1.0	23.8	4.2	3.9	3.8	3.9
EBL	36.8	36.9	36.6	36.4	30.5	87.0	60.0	59.0	55.6
EBT	29.3	29.4	63.3	79.8	353.3	111.1	82.2	1143.9	1110.6
EBR	1.6	2.1	18.2	5.2	353.3	1.1	1.0	4.7	41.7
WBL	23.7	23.7	12.3	12.3	21.8	55.1	49.9	13.1	12.7
WBT	17.0	17.0	18.2	18.7	68.6	79.7	77.6	79.0	78.7
WBR	9.0	11.0	1.3	2.1	68.6	0.8	0.7	0.8	0.8
Movement	**Queue Length divided by Spacing**								
EBTS	3.0%	3.8%	51.7%	71.5%	0.0%	3.3%	1.4%	3.8%	4.6%
WBTS	2.5%	3.4%	5.4%	11.5%	0.0%	0.5%	0.2%	0.1%	0.1%
Movement	**Maximum Queue Length divided by Storage**								
EBL	n/a	n/a	n/a	n/a	n/a	317%	116%	70%	50%
WBL	n/a	n/a	n/a	n/a	n/a	213%	88%	38%	26%

Appendix F. Delay Simulation Results

Table F1: v/c = 0.7; OD Pattern: Superstore										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	21.9	20.7	31.4	28.9	26.9	27.0	24.8	37.7	39.8
	WBT	24.1	23.8	26.8	25.1	33.2	27.3	26.7	29.7	29.8
Minor to Minor	NBT	38.8	38.7	30.5	30.9	30.0	56.8	64.9	49.0	48.2
	SBT	43.1	44.2	44.1	45.2	29.4	44.6	46.4	35.6	35.9
Main to Minor	EBL	46.2	46.2	44.4	44.2	57.2	62.1	67.3	101.2	96.6
	EBR	16.7	17.0	19.4	18.0	20.6	5.8	5.7	6.9	7.3
	WBL	41.4	41.4	28.1	28.1	46.7	55.4	49.4	45.9	42.7
	WBR	18.1	18.6	22.3	20.7	25.4	9.6	9.4	9.9	9.9
Minor to Main	NBL	46.7	50.9	39.4	43.4	44.4	22.3	22.3	38.0	37.9
	NBR	4.8	4.9	4.6	4.6	7.8	17.0	16.5	15.4	16.6
	SBL	50.6	54.2	51.7	56.3	90.6	26.8	26.8	47.2	47.3
	SBR	4.5	4.5	4.2	4.4	17.3	15.0	15.1	12.4	12.4
Bicycle										
Main to Main	EBT	13.0	13.3	20.0	19.6	20.1	19.7	18.8	26.2	25.0
	WBT	18.1	18.5	18.5	18.8	25.9	20.9	20.7	23.8	23.4
Minor to Minor	NBT	17.9	18.8	18.8	20.0	25.2	17.4	18.8	32.1	31.5
	SBT	17.5	17.9	18.7	19.6	20.6	17.5	17.3	32.4	33.9
Main to Minor	EBL	17.9	17.9	18.4	18.5	64.0	45.4	35.4	35.9	33.4
	EBR	0.5	0.6	0.7	0.9	1.7	0.5	0.5	1.8	1.7
	WBL	19.2	19.1	18.8	18.9	59.4	50.5	40.8	54.8	46.9
	WBR	0.5	0.7	0.7	0.9	4.2	0.8	0.8	1.8	1.7
Minor to Main	NBL	23.2	28.7	23.4	30.4	63.3	17.6	17.5	32.0	32.1
	NBR	0.6	0.6	0.7	0.7	4.1	1.7	1.2	2.5	2.1
	SBL	21.8	24.6	23.9	30.0	56.4	18.0	18.1	30.1	30.1
	SBR	0.8	0.8	0.7	0.7	1.1	0.2	0.2	1.0	0.9
Pedestrian										
Main St. Cross		93.1	93.1	93.8	93.8	93.3	93.6	93.9	131.1	131.1
Minor St. Cross		84.5	84.5	84.3	84.3	91.7	82.4	82.5	111.8	111.9
Diagonal Cross		105.1	105.2	106.0	106.0	153.3	106.4	106.7	151.9	151.9

Table F2: v/c = 0.7; OD Pattern: Hybrid Gas Station										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	24.2	23.1	25.1	22.9	31.3	24.3	23.8	49.0	54.0
	WBT	23.7	22.9	25.6	23.7	30.0	26.7	26.5	29.4	29.7
Minor to Minor	NBT	31.9	31.3	22.8	22.5	22.8	44.7	47.4	37.9	37.9
	SBT	32.5	32.9	23.9	23.9	23.2	40.8	42.8	27.0	27.4
Main to Minor	EBL	42.9	43.0	58.9	59.1	41.3	43.0	39.8	94.6	88.8
	EBR	17.3	17.1	21.0	19.8	26.7	6.6	6.6	12.4	12.5
	WBL	40.0	40.0	57.8	57.2	47.5	53.3	48.4	39.1	36.6
	WBR	15.3	15.2	19.3	18.3	23.5	6.0	6.0	6.0	6.0
Minor to Main	NBL	45.5	49.5	33.9	37.8	39.1	22.9	22.9	34.5	34.4
	NBR	6.4	6.3	5.8	6.3	8.2	18.2	18.8	21.2	21.0
	SBL	44.1	47.8	35.5	39.0	60.0	24.8	24.9	34.4	34.4
	SBR	4.5	4.5	4.1	4.4	8.0	13.3	13.3	11.0	11.0
Bicycle										
Main to Main	EBT	14.4	14.7	13.2	13.9	19.5	17.6	17.5	26.4	25.4
	WBT	16.1	16.4	15.9	16.2	22.4	19.2	19.3	21.0	20.8
Minor to Minor	NBT	17.7	18.2	14.0	14.5	20.5	17.5	18.1	25.9	26.2
	SBT	17.6	18.0	14.6	15.2	19.7	17.8	17.7	28.7	28.2
Main to Minor	EBL	18.1	18.1	13.3	13.4	54.3	43.0	34.0	32.8	33.5
	EBR	0.5	0.6	0.4	0.7	1.1	0.4	0.4	1.6	1.5
	WBL	19.2	19.2	13.9	13.8	54.8	48.1	39.4	50.9	42.9
	WBR	0.4	0.4	0.6	0.7	2.9	0.6	0.7	1.0	0.9
Minor to Main	NBL	21.8	26.7	19.7	26.1	55.2	18.0	18.2	28.6	28.6
	NBR	0.7	0.7	0.4	0.4	2.8	1.4	1.1	1.5	1.9
	SBL	22.2	25.3	19.1	25.5	51.5	18.0	18.3	27.3	27.3
	SBR	0.7	0.7	0.5	0.4	1.0	0.2	0.2	0.7	0.6
Pedestrian										
Main St. Cross		93.2	93.2	80.9	80.9	82.7	93.1	93.1	118.5	118.5
Minor St. Cross		84.8	84.7	72.5	72.5	84.1	82.8	82.8	101.9	102.0
Diagonal Cross		105.5	105.5	90.8	90.8	131.7	106.5	106.5	136.5	136.6

Table F3: v/c = 0.7; OD Pattern: ResAM										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (LRSplit)	-900 (LRSplit)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	19.8	21.8	23.9	22.3	34.7	23.9	24.1	40.0	43.1
	WBT	16.3	16.3	23.9	23.0	22.9	26.9	25.7	35.6	36.2
Minor to Minor	NBT	52.7	52.5	37.1	37.6	20.6	34.2	35.2	32.6	32.8
	SBT	49.2	48.2	32.2	32.4	28.4	52.5	52.1	30.7	32.5
Main to Minor	EBL	60.1	60.1	33.1	33.3	49.0	44.9	40.4	84.3	78.2
	EBR	15.6	15.9	16.6	16.3	29.4	7.2	7.2	8.2	8.1
	WBL	48.1	48.2	53.0	53.0	63.5	62.2	57.8	45.1	43.1
	WBR	9.6	9.5	14.0	14.3	17.7	6.1	5.4	8.5	8.7
Minor to Main	NBL	53.8	53.2	48.8	53.5	43.5	35.0	35.0	36.8	36.8
	NBR	4.4	4.4	4.3	4.6	6.4	12.2	12.4	15.9	16.9
	SBL	59.4	52.1	46.5	50.2	45.8	31.0	30.8	33.1	33.1
	SBR	5.9	5.7	7.1	7.1	13.1	17.4	15.8	14.1	14.5
Bicycle										
Main to Main	EBT	11.6	11.1	15.6	15.4	23.9	22.4	21.7	27.1	26.3
	WBT	6.0	6.4	12.3	11.9	15.4	14.5	14.6	21.0	20.8
Minor to Minor	NBT	33.6	33.6	21.7	22.5	18.1	27.7	27.7	25.9	26.2
	SBT	35.3	36.0	23.2	24.2	24.5	27.0	27.3	28.7	28.3
Main to Minor	EBL	35.4	35.4	22.3	22.2	53.9	59.7	50.7	33.1	33.8
	EBR	2.0	2.3	0.7	0.9	2.2	0.7	0.7	1.6	1.6
	WBL	38.2	38.1	23.1	23.1	64.6	55.3	46.6	51.2	42.9
	WBR	0.3	0.2	0.8	1.0	2.4	0.7	0.7	1.0	0.9
Minor to Main	NBL	36.2	37.4	27.2	34.0	49.4	26.4	26.5	28.5	28.4
	NBR	3.0	3.0	1.4	1.4	2.5	4.8	3.7	1.6	1.8
	SBL	48.4	56.2	28.6	35.2	61.6	27.1	27.5	27.3	27.2
	SBR	3.2	3.2	1.1	1.2	2.1	0.9	0.9	0.7	0.6
Pedestrian										
Main St. Cross		142.9	143.0	106.1	106.1	93.1	119.8	119.3	118.5	118.5
Minor St. Cross		123.0	123.0	91.9	92.0	91.9	103.2	103.5	101.6	101.8
Diagonal Cross		164.1	164.2	120.5	120.5	153.8	137.1	137.2	136.7	136.7

Table F4: v/c = 0.7; OD Pattern: ResPM										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	24.4	22.2	22.5	20.8	37.7	21.2	21.2	47.6	52.5
	WBT	21.3	20.1	23.7	22.8	24.4	36.4	35.4	30.3	30.6
Minor to Minor	NBT	30.0	30.6	34.6	34.7	20.4	37.7	41.6	35.1	34.9
	SBT	29.8	29.3	31.5	31.7	23.2	51.5	52.5	25.8	26.7
Main to Minor	EBL	40.2	40.3	35.8	35.8	40.8	31.2	29.0	92.0	86.0
	EBR	18.4	17.9	17.8	17.3	35.7	6.7	6.7	13.0	12.4
	WBL	47.1	47.1	48.6	48.6	50.7	76.4	71.2	40.5	37.9
	WBR	14.5	14.5	14.0	13.9	19.1	4.9	4.9	4.3	4.4
Minor to Main	NBL	40.1	44.0	45.6	49.7	39.1	27.8	27.8	34.9	34.9
	NBR	6.2	6.3	6.3	6.9	8.3	17.3	18.2	22.0	21.8
	SBL	41.2	44.8	44.6	47.9	42.7	25.7	25.5	29.2	29.2
	SBR	3.3	3.4	3.3	3.6	6.9	11.9	12.0	10.5	10.4
Bicycle										
Main to Main	EBT	13.6	14.9	13.7	13.6	19.7	17.0	16.4	26.7	25.7
	WBT	8.3	7.6	16.4	15.5	18.5	25.5	25.1	21.3	21.1
Minor to Minor	NBT	57.8	58.8	22.0	23.1	16.4	21.9	22.0	25.9	26.3
	SBT	61.2	62.9	22.7	23.7	20.1	22.7	23.5	28.6	28.3
Main to Minor	EBL	63.5	63.5	22.5	22.5	47.9	47.8	39.0	32.8	33.4
	EBR	6.4	7.0	0.8	0.9	1.2	0.6	0.6	1.6	1.6
	WBL	61.7	62.0	22.7	22.7	55.1	64.9	56.0	51.4	43.1
	WBR	0.9	0.8	0.9	1.2	2.2	2.0	1.9	1.0	1.0
Minor to Main	NBL	62.3	67.4	28.4	35.4	49.5	22.8	22.8	28.6	28.5
	NBR	12.3	12.3	1.2	1.2	1.8	2.8	2.0	1.5	1.7
	SBL	65.6	71.3	28.2	35.2	51.5	22.9	23.0	27.3	27.3
	SBR	12.5	12.5	1.2	1.2	1.1	0.4	0.4	0.7	0.6
Pedestrian										
Main St. Cross		216.7	216.7	106.2	106.2	83.7	106.7	107.0	118.5	118.5
Minor St. Cross		183.1	183.1	92.5	92.5	83.5	93.1	92.8	101.6	101.2
Diagonal Cross		256.1	256.2	120.6	120.6	132.2	122.1	122.1	136.5	136.4

Table F5: v/c = 0.7; OD Pattern: Realign										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	23.2	21.8	30.1	32.0	28.0	24.3	23.2	49.3	55.7
	WBT	21.8	20.4	18.9	19.0	26.1	28.6	28.2	31.2	31.4
Minor to Minor	NBT	33.6	34.8	44.1	37.6	24.7	50.2	52.9	37.9	37.2
	SBT	34.2	35.0	48.3	41.8	24.5	46.9	48.0	29.0	29.5
Main to Minor	EBL	43.4	43.4	55.6	47.7	41.2	47.1	43.9	93.6	88.8
	EBR	17.4	17.3	15.9	17.6	23.8	6.3	6.2	12.3	12.2
	WBL	41.3	41.5	33.5	28.9	41.9	62.4	57.6	41.6	39.3
	WBR	15.4	15.6	13.9	15.1	20.2	5.8	5.8	6.0	6.2
Minor to Main	NBL	41.6	45.5	49.1	48.8	38.5	27.4	27.4	32.9	32.9
	NBR	6.1	6.1	6.4	6.2	8.7	17.6	17.4	21.3	21.3
	SBL	42.6	46.2	59.4	57.2	62.9	30.3	30.2	34.0	34.0
	SBR	4.2	4.4	4.2	4.2	12.8	13.7	13.4	12.3	12.0
Bicycle										
Main to Main	EBT	13.0	13.1	19.0	20.0	18.1	18.5	17.9	27.0	26.2
	WBT	14.4	14.0	12.3	12.4	19.7	20.8	20.8	22.0	21.7
Minor to Minor	NBT	18.0	18.4	26.9	23.2	20.6	21.5	22.3	25.9	26.2
	SBT	17.7	18.1	26.6	24.6	19.3	23.1	23.2	28.8	28.3
Main to Minor	EBL	18.2	18.2	27.0	22.9	53.3	50.3	40.6	32.7	33.6
	EBR	0.4	0.5	1.2	1.2	1.0	0.5	0.5	1.6	1.5
	WBL	19.2	19.1	26.6	23.3	53.7	59.8	50.2	51.1	43.1
	WBR	0.4	0.3	1.0	1.1	2.4	1.4	1.4	1.1	1.1
Minor to Main	NBL	20.0	23.8	30.9	34.8	51.5	22.7	22.7	28.7	28.6
	NBR	0.7	0.7	1.8	1.4	2.5	3.2	2.1	1.6	1.8
	SBL	20.5	23.2	32.9	34.8	49.9	23.3	23.5	27.3	27.3
	SBR	0.8	0.8	1.9	1.2	1.1	0.5	0.5	0.7	0.6
Pedestrian										
Main St. Cross		93.1	93.1	117.3	105.8	83.0	107.1	107.0	118.4	118.4
Minor St. Cross		84.1	84.1	102.8	92.0	83.9	93.2	93.2	102.2	101.7
Diagonal Cross		105.7	105.7	136.5	120.1	132.0	122.1	122.1	136.5	136.5

Table F6: v/c = 0.9; OD Pattern: Superstore										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	25.2	24.6	38.4	36.3	52.2	36.5	28.3	58.8	61.1
	WBT	24.6	24.6	26.6	25.4	40.7	34.5	32.4	32.3	32.5
Minor to Minor	NBT	47.8	48.4	37.7	37.8	26.0	59.7	63.5	49.5	49.0
	SBT	63.9	65.0	65.0	80.5	29.7	52.3	53.7	37.2	38.0
Main to Minor	EBL	58.4	58.3	54.6	54.6	78.0	65.7	57.6	115.3	109.5
	EBR	20.0	20.6	26.4	25.0	53.6	15.4	11.8	29.8	29.5
	WBL	45.3	45.3	31.7	31.7	74.7	74.9	67.8	47.5	44.5
	WBR	19.0	20.0	20.9	20.6	36.1	12.0	11.7	10.9	11.0
Minor to Main	NBL	56.2	60.2	46.7	50.8	38.6	33.5	33.3	40.3	40.4
	NBR	8.9	8.8	8.7	8.7	10.4	23.7	21.4	25.5	25.0
	SBL	72.2	76.1	74.3	92.4	157.5	39.7	39.9	46.6	46.6
	SBR	6.2	6.3	5.7	6.5	17.7	16.0	15.6	14.3	14.5
Bicycle										
Main to Main	EBT	14.4	14.3	20.8	21.1	20.2	22.8	20.7	27.1	25.7
	WBT	16.6	16.9	17.8	17.6	24.6	24.6	23.7	22.9	22.9
Minor to Minor	NBT	21.8	22.9	22.5	23.7	20.6	26.6	27.9	31.8	31.5
	SBT	23.2	23.7	23.6	25.0	19.9	26.2	27.2	31.8	34.2
Main to Minor	EBL	22.6	22.6	22.4	22.4	57.0	58.5	49.0	36.3	34.4
	EBR	0.7	1.0	0.8	1.3	1.2	0.7	0.7	2.1	2.1
	WBL	22.3	22.3	22.7	22.7	56.3	69.0	58.2	55.7	47.6
	WBR	0.4	0.8	0.9	1.3	3.0	1.4	1.4	1.6	1.6
Minor to Main	NBL	28.5	34.9	28.2	35.3	55.6	26.7	26.3	32.1	32.0
	NBR	0.9	0.9	1.1	1.1	2.8	5.0	3.0	2.1	2.1
	SBL	26.7	31.7	28.1	34.7	51.1	27.8	27.7	30.2	30.2
	SBR	1.3	1.3	1.3	1.3	1.0	0.9	0.8	0.9	0.8
Pedestrian										
Main St. Cross		105.4	105.4	106.5	106.5	82.9	119.7	119.4	130.6	130.6
Minor St. Cross		91.5	91.6	92.4	92.4	84.1	103.3	103.4	111.2	110.9
Diagonal Cross		120.6	120.6	121.1	121.2	132.0	136.8	137.0	151.3	151.4

Table F7: v/c = 0.9; OD Pattern: Hybrid Gas Station										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	24.6	24.1	25.1	24.2	157.2	24.6	24.2	64.8	66.1
	WBT	22.4	22.4	30.6	30.2	33.9	51.3	47.7	28.7	29.2
Minor to Minor	NBT	46.7	46.4	40.0	40.0	24.5	43.0	46.2	44.5	43.8
	SBT	46.9	47.2	42.0	42.7	23.8	54.8	55.1	32.5	33.4
Main to Minor	EBL	53.8	53.8	37.6	37.6	95.7	34.4	31.7	116.7	110.5
	EBR	18.8	19.2	19.7	19.7	164.2	10.7	10.6	36.1	34.0
	WBL	50.7	50.7	48.6	48.5	59.7	96.7	87.4	45.8	42.1
	WBR	14.9	15.3	17.1	17.6	29.7	14.4	12.5	6.8	7.0
Minor to Main	NBL	60.4	64.4	54.0	58.8	41.6	33.4	33.3	40.2	40.2
	NBR	10.2	10.2	10.1	10.4	10.4	21.6	21.8	26.6	26.2
	SBL	61.3	64.9	55.7	59.7	63.1	35.6	35.5	40.4	40.4
	SBR	6.0	6.0	6.2	6.4	9.1	13.6	13.0	12.1	12.0
Bicycle										
Main to Main	EBT	14.5	14.3	13.7	13.9	20.1	18.8	18.2	26.3	25.1
	WBT	14.5	14.4	20.3	20.6	22.2	29.6	29.3	20.7	20.9
Minor to Minor	NBT	26.7	27.5	28.1	30.0	20.5	25.9	27.2	31.8	31.7
	SBT	26.7	27.4	26.7	27.5	20.1	26.0	27.8	32.4	33.7
Main to Minor	EBL	27.3	27.3	27.6	27.6	54.4	54.9	45.3	35.7	33.6
	EBR	1.3	1.3	1.2	1.4	1.2	0.5	0.5	1.7	1.7
	WBL	27.8	27.7	27.4	27.2	55.6	76.1	66.6	55.1	46.9
	WBR	0.4	0.7	1.2	1.5	2.7	2.1	2.1	1.3	1.3
Minor to Main	NBL	30.2	35.9	31.8	38.7	54.4	27.0	26.7	32.4	32.4
	NBR	1.5	1.5	1.9	1.9	2.6	4.4	3.2	2.3	2.3
	SBL	30.6	35.6	31.9	38.7	52.5	27.2	27.3	30.3	30.3
	SBR	1.9	1.9	2.0	2.0	1.2	0.8	0.7	1.0	0.9
Pedestrian										
Main St. Cross		118.5	118.5	118.2	118.1	83.1	118.2	118.5	131.2	131.1
Minor St. Cross		103.2	103.2	103.1	103.2	84.2	102.5	102.8	111.7	111.8
Diagonal Cross		135.7	135.6	137.0	137.0	131.7	136.9	136.8	152.0	152.0

Table F8: v/c = 0.9; OD Pattern: ResAM										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (LPSplit)	-900 (LPSplit)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	21.6	23.8	28.1	26.6	123.7	27.9	28.0	45.3	50.6
	WBT	18.5	18.5	24.1	24.1	26.0	75.1	48.1	143.1	129.0
Minor to Minor	NBT	61.7	61.8	49.1	57.0	22.7	34.5	37.0	28.8	28.6
	SBT	49.6	48.5	39.2	39.6	33.0	62.1	61.9	34.8	39.6
Main to Minor	EBL	68.3	68.5	37.1	37.1	77.4	39.4	35.6	81.5	75.9
	EBR	19.7	20.0	20.3	19.8	131.3	10.9	10.9	14.7	14.5
	WBL	57.7	57.5	48.1	48.1	64.8	113.9	82.3	151.1	135.0
	WBR	11.6	11.4	16.8	17.5	23.3	45.5	24.5	108.9	95.6
Minor to Main	NBL	64.1	63.7	59.7	69.9	54.7	37.9	37.9	39.1	39.1
	NBR	5.9	5.8	6.1	6.6	7.9	14.6	15.0	20.3	20.5
	SBL	60.1	52.6	52.0	55.3	53.9	29.2	28.9	33.1	33.1
	SBR	8.0	8.4	11.2	10.6	17.3	28.8	22.5	17.1	18.0
Bicycle										
Main to Main	EBT	11.7	11.3	18.1	17.9	28.2	25.0	24.5	27.3	26.4
	WBT	6.0	6.3	10.7	10.3	15.8	18.0	17.5	21.2	21.0
Minor to Minor	NBT	33.2	33.2	26.6	27.2	20.7	26.6	27.4	25.8	26.2
	SBT	35.3	36.1	27.1	28.5	27.7	27.0	27.6	28.2	27.9
Main to Minor	EBL	35.4	35.4	27.7	27.7	57.9	61.8	53.4	32.9	34.1
	EBR	2.0	2.3	1.3	1.7	3.2	0.9	0.9	1.6	1.6
	WBL	37.6	37.6	26.8	26.6	71.8	56.6	48.8	51.0	43.0
	WBR	0.3	0.2	0.9	1.0	2.4	0.8	0.8	1.0	1.0
Minor to Main	NBL	36.0	37.3	30.4	37.5	53.0	26.1	26.4	28.3	28.3
	NBR	3.0	3.0	1.8	1.7	3.0	4.7	3.3	1.5	1.7
	SBL	48.7	56.5	32.9	39.6	71.5	27.0	26.8	27.3	27.3
	SBR	3.2	3.2	2.1	2.1	2.8	1.0	0.9	0.7	0.6
Pedestrian										
Main St. Cross		143.0	143.0	119.3	119.3	103.2	119.1	118.9	118.5	118.5
Minor St. Cross		123.3	123.5	103.7	103.9	102.3	103.9	103.2	101.5	101.3
Diagonal Cross		164.0	164.0	136.3	136.4	173.5	137.2	137.2	136.4	136.4

Table F9: v/c = 0.9; OD Pattern: ResPM										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	23.6	22.3	24.6	23.1	214.6	24.0	23.9	173.0	151.7
	WBT	19.5	18.9	37.3	37.1	24.1	83.8	75.6	32.4	32.9
Minor to Minor	NBT	43.3	44.3	44.1	47.4	21.1	42.9	47.6	35.3	35.3
	SBT	43.9	42.9	36.8	36.8	23.4	63.9	64.0	27.1	27.9
Main to Minor	EBL	52.3	52.3	27.6	27.5	138.5	30.6	28.6	208.7	177.8
	EBR	18.8	18.6	20.0	19.6	222.2	11.0	11.0	135.9	109.6
	WBL	57.8	57.8	55.4	55.2	57.2	135.4	122.7	41.8	39.6
	WBR	13.4	13.8	16.0	16.8	19.1	36.3	31.1	5.9	6.1
Minor to Main	NBL	54.6	58.3	56.4	63.1	45.4	34.1	34.2	35.7	35.7
	NBR	10.5	10.3	9.9	10.7	10.0	22.2	23.2	25.7	26.1
	SBL	58.5	61.9	52.3	55.4	43.2	30.9	31.0	29.2	29.2
	SBR	4.8	4.9	4.9	4.9	7.5	13.1	12.2	11.6	11.5
Bicycle										
Main to Main	EBT	13.6	13.1	13.2	13.7	20.2	18.3	17.5	27.0	25.9
	WBT	11.5	11.5	23.1	24.2	17.5	30.5	30.6	21.3	21.1
Minor to Minor	NBT	25.9	26.4	26.7	28.6	16.6	25.6	28.0	26.0	26.2
	SBT	26.8	27.4	26.9	28.1	20.0	25.6	27.7	28.6	28.0
Main to Minor	EBL	27.5	27.4	27.5	27.5	48.0	54.6	45.1	32.5	33.6
	EBR	1.1	1.3	1.0	1.4	1.2	0.6	0.6	1.5	1.4
	WBL	27.4	27.3	27.3	27.2	54.6	76.8	67.5	51.1	43.1
	WBR	0.3	0.2	1.5	1.7	2.1	2.3	2.3	1.0	1.0
Minor to Main	NBL	27.7	31.4	32.5	39.3	48.7	27.4	27.3	28.6	28.6
	NBR	1.6	1.6	2.0	2.0	1.8	4.1	3.3	1.5	1.8
	SBL	30.6	36.0	32.7	39.5	53.2	27.2	27.4	27.3	27.3
	SBR	2.0	2.0	2.0	2.1	1.1	0.7	0.8	0.7	0.6
Pedestrian										
Main St. Cross		118.1	118.1	117.8	117.9	83.2	118.3	118.3	118.5	118.5
Minor St. Cross		103.4	103.5	103.0	103.0	83.4	102.3	102.0	102.1	101.9
Diagonal Cross		136.2	136.2	136.9	136.9	131.5	136.8	137.0	136.4	136.3

Table F10: v/c = 0.9; OD Pattern: Realign										
Movement		Simulated Delay (sec) for each Spacing Level								
		-1200 (3Lead)	-900 (3Lead)	-600 (3Lag)	-300 (3Lag)	0 (4C)	+300 (T3Lag)	+600 (T3Lag)	+900 (4CSplit)	+1200 (4CSplit)
Vehicle										
Main to Main	EBT	22.6	21.8	83.7	70.1	74.9	33.0	25.0	207.5	207.8
	WBT	21.1	20.5	22.7	21.6	30.6	34.8	33.4	34.2	34.4
Minor to Minor	NBT	52.3	53.9	46.6	48.4	26.2	66.2	64.7	40.6	40.1
	SBT	66.2	67.9	172.4	448.7	25.9	62.9	62.2	32.6	33.7
Main to Minor	EBL	51.0	51.0	50.4	50.4	56.6	61.0	47.7	248.0	235.9
	EBR	17.4	18.0	60.1	41.9	75.7	12.5	9.5	162.6	159.5
	WBL	50.5	50.6	27.4	27.3	46.5	80.6	74.1	43.3	41.2
	WBR	16.4	17.3	16.0	16.3	25.2	8.8	8.7	8.8	8.8
Minor to Main	NBL	57.3	61.1	52.1	56.0	38.9	31.7	31.6	33.7	33.7
	NBR	9.6	9.6	9.5	8.9	10.8	25.7	21.8	24.5	24.6
	SBL	74.3	78.2	184.7	456.7	73.9	36.9	36.9	36.0	36.0
	SBR	6.1	6.2	8.1	19.0	15.4	16.3	15.6	14.6	15.0
Bicycle										
Main to Main	EBT	12.5	12.1	24.2	24.0	19.5	19.2	18.6	27.2	26.6
	WBT	13.6	13.4	14.2	13.1	21.2	22.6	22.7	23.0	22.6
Minor to Minor	NBT	26.6	27.2	27.1	28.5	20.4	26.2	27.9	25.8	26.0
	SBT	26.1	26.6	27.0	28.5	19.4	26.1	27.7	29.0	28.5
Main to Minor	EBL	27.4	27.4	27.4	27.6	55.7	55.4	45.9	33.1	33.7
	EBR	1.1	1.2	1.7	1.9	1.2	0.7	0.7	1.6	1.6
	WBL	27.9	27.8	27.4	27.3	55.0	68.4	59.0	50.8	43.1
	WBR	0.4	0.7	1.0	1.2	2.6	1.3	1.2	1.3	1.2
Minor to Main	NBL	29.6	34.8	30.6	37.1	51.7	27.1	27.0	28.8	28.9
	NBR	1.6	1.6	1.8	1.8	2.7	4.3	3.2	1.5	1.7
	SBL	29.2	33.2	33.2	40.4	50.0	27.5	27.3	26.9	26.9
	SBR	1.9	1.9	2.0	2.1	1.0	0.7	0.8	0.6	0.6
Pedestrian										
Main St. Cross		119.3	119.3	117.6	117.5	82.6	118.4	118.4	118.7	118.7
Minor St. Cross		102.6	102.5	102.8	102.7	83.2	102.2	102.2	102.3	101.9
Diagonal Cross		135.5	135.6	137.2	137.4	131.3	136.9	136.8	137.1	137.1

Appendix E. Analysis of Variance (ANOVA) of Recommendations

The Analysis of Variance (ANOVA) statistical test was applied on the delay measure of several key movements (i.e., major street through and left turn movements) to verify that the recommended offset T-intersection configurations outperforms a regular 4-Leg intersection. Testing results for each development scenario are presented below.

Appendix E1. Superstore (LR offset with a spacing of 900 ft.)

v/c Ratio	Delay	EBT		EBL		WBT		WBL	
		LR	4-Leg	LR	4-Leg	LR	4-Leg	LR	4-Leg
0.7	Avg	20.73	26.9	46.23	57.15	23.83	33.16	41.38	46.69
	S.D.	0.88	1.45	4.28	5.85	1.47	1.39	3.36	2.92
	ANOVA	F=397.236 P=0.000		F=68.088 P=0.000		F=638.032 P=0.000		F=42.687 P=0.000	
0.9	Avg	24.61	52.16	58.3	78	24.58	40.67	45.29	74.68
	S.D.	1.03	13.29	7.32	19.38	0.87	4.08	2.45	21.65
	ANOVA	F=128.149 P=0.000		F=27.129 P=0.000		F=446.274 P=0.000		F=54.586 P=0.000	

Appendix E2: Hybrid Gas Station (LR offset with a spacing of 300 ft.)

v/c Ratio	Delay	EBT		EBL		WBT		WBL	
		LR	4-Leg	LR	4-Leg	LR	4-Leg	LR	4-Leg
0.7	Avg	22.87	31.32	59.12	41.31	23.72	30.02	57.18	47.48
	S.D.	0.97	2.25	10.74	1.95	0.91	1.37	13.42	5.92
	ANOVA	F=356.810 P=0.000		F=79.865 P=0.000		F=440.185 P=0.000		F=13.120 P=0.001	
0.9	Avg	24.18	157.23	37.62	95.65	30.18	33.88	48.48	59.74
	S.D.	1.22	41.07	2.67	29.28	1.78	1.86	2.88	9.73
	ANOVA	F=314.571 P=0.000		F=116.866 P=0.000		F=61.964 P=0.000		F=36.940 P=0.000	

Note: Cells highlighted in yellow means 4-Leg intersection outperforms Offset T-Intersection

Appendix E3: Residential Area AM Period (LR offset with a spacing of 600 ft.)									
v/c Ratio	Delay	EBT		EBL		WBT		WBL	
		LR	4-Leg	LR	4-Leg	LR	4-Leg	LR	4-Leg
0.7	Avg	23.94	34.74	33.06	49.03	23.87	22.92	53.03	63.55
	S.D.	0.81	1.92	5.89	8.44	2.43	0.85	7.63	14.76
	ANOVA	F=805.803 P=0.000		F=72.232 P=0.000		F=4.084 P=0.048		F=12.026 P=0.001	
0.9	Avg	28.15	123.71	37.1	77.37	24.07	25.99	48.1	64.85
	S.D.	1.03	50.66	7.65	26.08	1.88	1.18	7.64	11.68
	ANOVA	F=106.700 P=0.000		F=65.860 P=0.000		F=22.447 P=0.000		F=48.523 P=0.000	

Appendix E4: Residential Area AM Period (LR offset with a spacing of 600 ft.)									
v/c Ratio	Delay	EBT		EBL		WBT		WBL	
		LR	4-Leg	LR	4-Leg	LR	4-Leg	LR	4-Leg
0.7	Avg	22.53	37.73	35.8	40.79	23.74	24.41	48.59	50.74
	S.D.	0.77	4.31	3.39	3.38	0.94	1.34	3.63	5.95
	ANOVA	F=361.584 P=0.000		F=32.597 P=0.000		F=5.027 P=0.029		F=2.855 P=0.096	
0.9	Avg	83.68	214.65	50.42	138.53	22.68	24.11	27.43	57.17
	S.D.	16.21	25.23	3.15	21.88	1.46	1.41	3.5	10.01
	ANOVA	F=572.206 P=0.000		F=476.615 P=0.000		F=14.891 P=0.000		F=235.963 P=0.000	

Appendix E5: Realign (LR offset with a spacing of 900 ft.)									
v/c Ratio	Delay	EBT		EBL		WBT		WBL	
		LR	4-Leg	LR	4-Leg	LR	4-Leg	LR	4-Leg
0.7	Avg	21.78	28.05	43.41	41.21	20.41	26.1	41.48	41.94
	S.D.	1.01	1.54	3.21	2.51	0.86	1.18	2.62	2.93
	ANOVA	F=347.727 P=0.000		F=8.745 P=0.004		F=455.574 P=0.000		F=0.411 P=0.524	
0.9	Avg	21.79	74.87	51.03	56.6	20.54	30.61	50.56	46.55
	S.D.	1.03	31.72	2.65	15.15	0.97	1.31	3.71	4.32
	ANOVA	F=83.919 P=0.000		F=3.935 P=0.052		F=1144.956 P=0.000		F=14.877 P=0.000	

Note: Cells highlighted in yellow means 4-Leg intersection outperforms Offset T-Intersection; red numbers mean the difference is not significant at the 0.05 significance level.