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Analysing delay and queue length using microscopic simulation for the unconventional intersection design Superstreet

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With the increasing demand on today's roadway systems, intersections are beginning to fail at alarming rates prior to the end of their design periods. Therefore, maintaining safety and operational efficiency at intersections on arterial roadways remains a constant goal. This effort for sustainability has spawned the creation and evaluation of numerous types of unconventional intersection designs. Several unconventional designs exist and have been studied, including the Bowtie, Continuous Flow Intersection, Paired Intersection, Jughandle, Median U-Turn, Single Quadrant Roadway and Superstreet Median. Typically, these designs eliminate/reroute conflicting left-turn manoeuvres to and from the minor or collector cross road. High left-turning volumes are addressed by adding an exclusive left-turning signal. This consequently increases the required number of signal phases and shorter green time for the major through traffic. This paper describes the evaluation of an unconventional intersection designed to lessen the effects of high left-turning traffic. To aid in the evaluation of the unconventional Superstreet design, a comparison of a Conventional intersection's operation was made. Constructing and analysing a live Superstreet and Conventional intersection design is a massive undertaking. Microscopic traffic models were developed and tested using CORSIM. A variety of scenarios were created by changing the approach volumes and turning percentages on the major/minor roads to reflect different congestion levels that may occur at the intersection on any given day. The total number of created scenarios was 72, i.e. 36 scenarios for each design. Among the general findings of this research was that the Conventional design consistently showed evidence of higher delay time and longer queue length compared to the Superstreet intersection design. The reduction in the network delay ranged from 27.39% to 82.26%, and an approximate 97.5% reduction in average network queue length experienced on the major road's through lanes when the Superstreet design was implemented. This is a significant reduction, especially since the through lane volume of the major road is relatively high. These results are assumed to be due to the additional available green time for the Superstreet intersection design.

INTRODUCTION

On a typical four-leg intersection, one of two intersecting roads services the higher traffic volume. This roadway is referred to as the major or arterial road. The second roadway, which services the lower traffic volume, is referred to as the minor or collector road. When the volume on either road nears capacity, queues begin to form, raising the potential for crashes and unsafe driving manoeuvres. For this reason improving safety and operational efficiency at intersections on arterial roadways remains a constant goal. The Federal Highway Administration (FHWA 2004) studies have shown that conventional methods of adding capacity to an intersection have diminishing results. For instance, the addition of a second through lane adds 15 years to the life of the

intersection before it reaches capacity; the addition of a third through lane adds only ten years; and a fourth through lane adds only six years. Simply put, the increase in supply decreases the overall design life. Drivers attracted to the seemingly more efficient road eventually yield larger demand at a faster rate.

The demand increase at large intersections can result in longer clearance intervals, more protected left-turn phasing, longer pedestrian clearance times, greater imbalances in lane utilisation, and potential queue blockage caused by the resulting longer cycle length (FHWA 2004). Combined, these factors increase loss time and potential for signal failure, and warrant the need to study and evaluate alternative methods.

In an attempt to improve the operational efficiency and safety characteristics

Table 1 Simulation models

Simulation model	Classification	Use
TRANSIMS	Large-scale microscopic	Modelling regions with several millions
CORSIM	microscopic	Modelling urban traffic conditions and advanced traffic control scenarios
VISSIM	mesoscopic	Modelling complex dynamic systems such as transit signal
INTRAS	microscopic	Modelling traffic conditions on freeways, ramps and highway segments
INTEGRATION	microscopic	Simulating both freeways and arterials, and evaluating ITS scenarios
MASSVAC	macroscopic	Forecasting hurricane evacuation performance
MITSIMLab	microscopic	Model traffic operations
TransCAD	macroscopic	Conventional static model
Tranplan	macroscopic	Conventional static model
EMME/2	macroscopic	Conventional static model
Dynasmart-P	mesoscopic	Model route choice behaviour
OREMS	microscopic	Model emergency and disaster evacuation
DYNEV	macroscopic	Enhanced to model regional hurricane planning process
NETVAC	macroscopic	Evacuation model
CTM	macroscopic	Evacuation model
PARAMICS	microscopic	Provides complete visual display
CORFLO	macroscopic	Simulates design control devices
GETRAM	microscopic	Simulates traffic and human behaviour

of intersections, past research has explored several types of unconventional intersection designs. Several unconventional designs exist and have been studied, including the Bowtie, Continuous Flow Intersection, Continuous Green-T, Parallel Flow Intersection, Paired Intersection, Jughandle, Median U-Turn, Single Quadrant Roadway, Split Intersection, Roundabouts and Superstreet Median Crossover. These designs are referred to as “unconventional” because they incorporate geometric features or movement restrictions that would normally be allowed at standard intersections. Typically, these designs eliminate/reroute conflicting left-turn manoeuvres to and from the minor or collector cross road. High left-turning volumes are often addressed by adding an exclusive left-turning signal. Unfortunately the addition of a left-turn signal increases the required number of signal phases and shortens green time for the major through traffic, thereby increasing queue formation. Reducing the number of signal phases would improve the overall operation and safety of the intersection by enhancing capacity (with an increase in effective green) and reducing delay when the number of signal phases is reduced (Bared and Kaisar 2002; Reid and Hummer 1999).

This paper describes the evaluation of an unconventional intersection design created to decrease the effects of high left-turning traffic. To aid in the evaluation of the unconventional design named Superstreet, a comparison to a Conventional intersection's operation was performed. Constructing a live Superstreet and Conventional intersection design for evaluation reasons is a massive undertaking and not feasible in many circumstances. For this reason the two intersection designs were modelled and simulated using the microscopic traffic simulation model CORSIM (CORridor SIMulation).

CORSIM is a combination of NETSIM and FRESIM. NETSIM, originally called UTCS-1, is a component of CORSIM that is capable of representing complex urban networks. Following distance, lane changing, turning movements, overtaking and driving behaviour are governed by this component of CORSIM. Many Measures of Effectiveness (MOEs) are outputted by NETSIM, including stopped delays, queue lengths, signal phase failures, fuel consumption. FRESIM is another component of CORSIM that is capable of representing complex freeway systems. CORSIM is capable of simulating freeway and surface street operations simultaneously (Papacostas & Prevedouras 2001).

LITERATURE REVIEW

Traffic simulation modelling

Traffic micro-simulation models are widely used to qualify and evaluate the benefits and limitations of traffic operation alternatives. Boxill and Yu (2000) classify traffic simulation models as microscopic, mesoscopic and macroscopic. Models that simulate individual vehicles at small time intervals are termed as microscopic, while models that aggregate traffic flow are termed as macroscopic. Mesoscopic refers to models in-between microscopic and macroscopic. The main disadvantage of microscopic simulation models is the extensive data required and the need for advanced computer resources. Microscopic simulation has been used for a long time to simulate project scale cases such as intersection design. What is new about microscopic simulation is that it is now possible to be used at a regional scale, such as simulating hurricane evacuation for a whole region with several million inhabitants (Nagel & Rickert 2000). Table 1 illustrates the most commonly used simulation models found in literature.

Previous work

The FHWA (2004) informational guide for signalised intersections classifies intersection

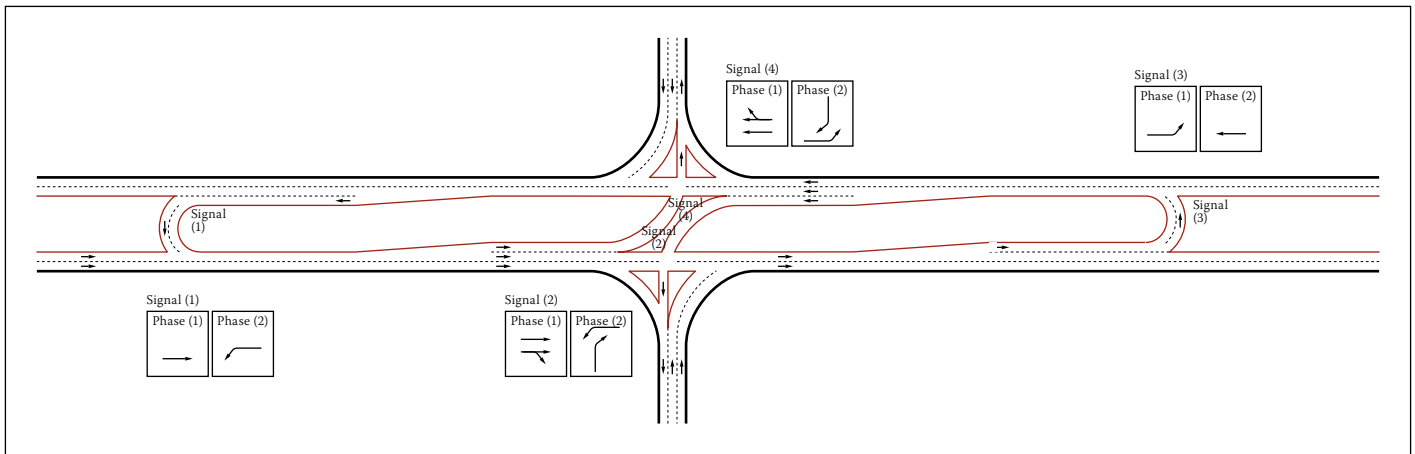


Figure 1 Superstreet

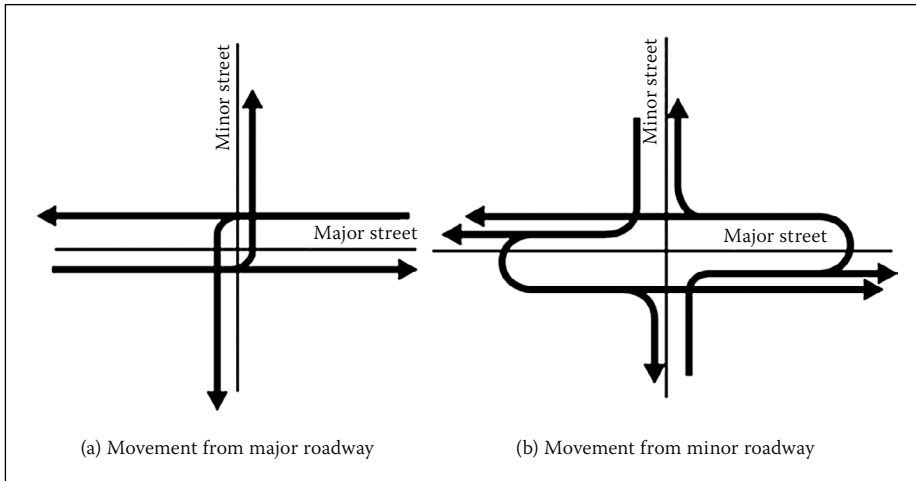


Figure 2 Vehicular movements at a Superstreet Median Crossover (Source: FHWA 2004)

treatments into three kinds: (1) intersection reconfiguration, (2) indirect left-turn treatments, including Jughandle, Median U-Turn, Superstreet, Continuous Flow Intersection (CFI) and Quadrant intersections, and (3) grade separation treatments. Reid and Hummer (1999) used CORSIM to compare traffic operations along an arterial road that has five signalised intersections for the Conventional Two-Way Left-Turn Lane (TWLTL) design, and two alternative unconventional designs, the Median U-Turn Crossover design and the Superstreet Median Crossover design. Results from the study indicate that the Median U-Turn and Superstreet designs improve system travel time and average speed in comparison with the TWLTL design, and overall there was a peak period travel time reduction of 17% when using the unconventional Median U-Turn and Superstreet designs.

Reid and Hummer (2001) later used CORSIM to compare the traffic performance of seven isolated unconventional intersection designs – the Quadrant, Median U-Turn, Superstreet Median Crossover, Bowtie, Jughandle, Split Intersection, and Continuous Flow Intersection. The simulation results showed that the Superstreet and Bowtie designs were only competitive with

the Conventional design when the cross streets configuration was two lanes.

Also, Kim *et al* (2007) used VISSIM to compare the performance of the Superstreet designs to the Conventional designs. The results showed that the Superstreet design is similar to the Median U-Turn design, but has some additional features that allow for through traffic progression on the major road in both directions by preventing the minor road traffic from crossing the major road.

Description of Superstreet

The Superstreet Median Crossover design, shown in Figure 1, is an extension of the Median U-Turn design. The Federal Highway Administration (FHWA 2004) reports that “the design of a Superstreet Median Crossover is similar to that of a Median U-Turn Crossover. Crossovers should be located approximately 180 m (600 ft) from the main intersection. A semi-trailer combination design vehicle would need a median width of 18 m (60 ft) to accommodate a U-Turn”.

Drivers are not allowed to turn left from the crossroad onto the major road. The through movement for the vehicles on the minor road is accomplished by turning right onto the major road, then making

a u-turn, and turning right again to the minor road (FHWA 2004). Figure 2 shows the vehicular movement at a Superstreet Median Crossover. Research has shown that forcing cross street traffic to turn right onto an arterial first, and then turning left back onto the cross street, is generally superior to a left-turn then-right pattern as seen on the Quadrant Roadside Intersection Design. These crossovers create difficult merges from the left arterial, and may only be useful when the cross street volume is small in comparison to the arterial road volume (Mahale *et al* 1986).

The Superstreet configuration allows each direction of the major street to operate as two separate three-approach intersections, and allows each direction of the major street to operate on an independent timing pattern. Therefore, two two-phase traffic signals are needed at the main intersection, one for each minor street approach. In addition, two two-phase signals are required at upstream/downstream median crossover. Since the signals of the major road may be controlled and timed independently of the minor street, it is possible to achieve a maximum amount of traffic progression in both directions of the major road. The major road’s through movement benefits the most from the Superstreet Median Crossover design. Left-turning movements are permitted directly from the major street, so they also benefit from decreased delay (FHWA 2004). A typical phasing diagram of the Superstreet Median Crossover design is also shown in Figure 1.

Safety

Conflict points provide a means of comparing relative safety for vehicles between the Conventional four-leg signalised intersection and the unconventional intersection. Superstreet Median Crossover creates a total of 20 conflict points compared to 32 conflict points created by the Conventional four-leg signalised intersection. Table 2 summarises the number of conflict points in a four-leg

signalised intersection and the number of conflict points in a Superstreet intersection design. Hummer and Jagannathan (2008) investigated the safety aspects of the Superstreet by analysing sites in Maryland and North Carolina. Results showed huge reductions in collision frequencies and rates.

Superstreet, Continuous Flow Intersections (CFI), Center Turn Overpass, and Roundabouts are believed to achieve significant reductions in accident frequency, accident severity, stopped delay, and queue length (Kim *et al* 2007). Noted advantages of the Superstreet design in particular have been:

1. Reduces four-phase signal to two-phase signal
2. Signals for opposite direction of travel can be timed for progression independently
3. Pedestrian-friendly.

The simplified signal phases are very effective for the progression of through traffic and for reducing delays at the intersection, which will save the overall travel time. Although these advantages have been cited numerous times, the degree to which the Superstreet operation is more advantageous than a Conventional intersection is not well known. Furthermore, the minor street vehicle types, and the crossing and turning volumes vary by location, which makes evaluating and comparing these two intersection designs at a live and active intersection difficult.

The following sections describe the methods used, as well as the results of a comparison between a Superstreet intersection and a Conventional intersection using simulation. Delay and queue lengths were the primary measures of effectiveness used in the evaluation. Delay is arguably the most frequently experienced and troublesome aspect of travel for motorists, while the hazards associated with queue length are a constant concern for city and state traffic officials.

METHODOLOGY

The proposed methodology for the operational evaluation and comparison between a Superstreet intersection and a traditional four-leg intersection was conducted using CORSIM platform. The two intersections used in the analysis were formed by two roadways, arterial and collector, crossing at a 90 degree angle. For simplicity, each leg of the intersection was considered to be level. The design of each leg was extended approximately 1 000 feet from the centre of the intersection. Each intersection was designed in accordance with the Policy on Geometric Design of Highways and Streets (AASHTO) standards for a passenger vehicle, and a

Table 2 Number of conflict points at a four-leg signalised intersection compared to a Superstreet Crossover (Source: FHWA 2004)

Conflict type	Four-leg signalised intersection	Superstreet Median Crossover
Merging/diverging	16	18
Crossing (left turn)	12	2
Crossing (angle)	4	0
Total	32	20

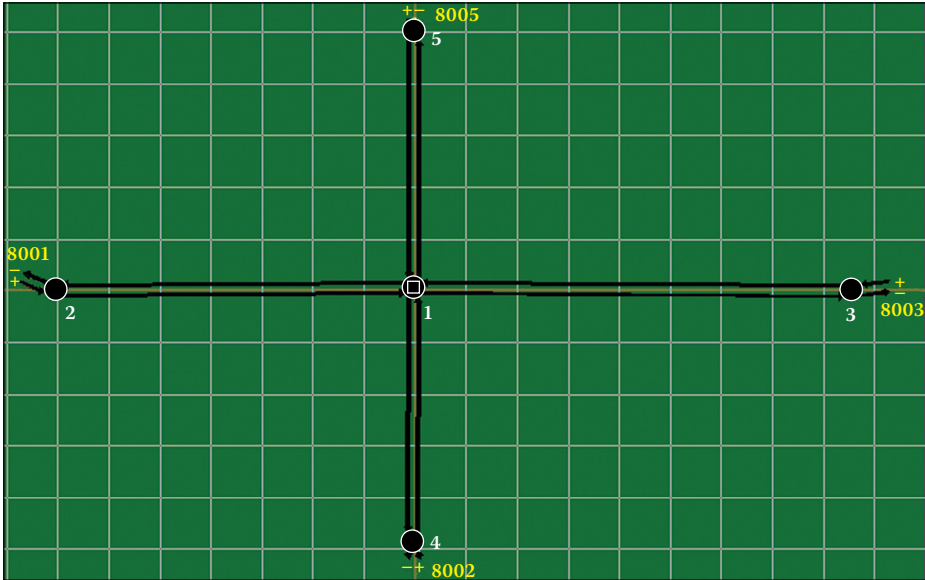


Figure 3 Conventional CORSIM design model

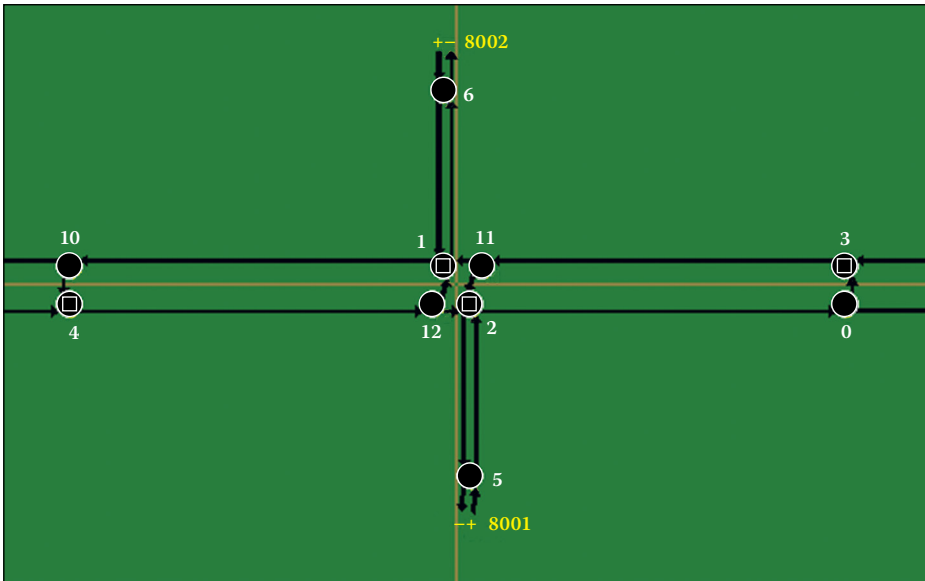


Figure 4 Superstreet CORSIM design model

design speed of 45 mph. Lane width was considered to be 12 ft and shoulder width was considered to be 4 ft (AASHTO 2004). The design was completed using computer aided design (CAD) software, and then it was imported into traffic simulation software.

The development of the CORSIM microscopic model for the two intersection designs involved primary component steps, including the following:

1. Intersections design
2. Signalisation

3. Developing alternative scenarios
 4. Analyses and comparison of all scenarios using appropriate measures.
- Model calibration and validation are necessary and critical steps in any model application. However, the primary limitation to the CORSIM model development was the lack of real intersection data to support calibration and validation of the model. The following sections will discuss the details and approach to completing each step listed above.

Table 3 Simulation scenarios summary

Simulation scenario	Arterial Roadway				Collector Roadway			
	Traffic volume (pcph)	Turning movement (%)			Traffic volume (pcph)	Turning movement (%)		
		Left	Through	Right		Left	Through	Right
1	1 800	10	75	15	600	30	50	20
2						20	60	20
3						15	65	20
4	1 800	15	70	15	600	30	50	20
5						20	60	20
6						15	65	20
7	1 800	20	65	15	600	30	50	20
8						20	60	20
9						15	65	20
10	1 800	10	75	15	800	30	50	20
11						20	60	20
12						15	65	20
13	1 800	15	70	15	800	30	50	20
14						20	60	20
15						15	65	20
16	1 800	20	65	15	800	30	50	20
17						20	60	20
18						15	65	20
1	2 400	10	75	15	600	30	50	20
2						20	60	20
3						15	65	20
4	2 400	15	70	15	600	30	50	20
5						20	60	20
6						15	65	20
7	2 400	20	65	15	600	30	50	20
8						20	60	20
9						15	65	20
10	2 400	10	75	15	800	30	50	20
11						20	60	20
12						15	65	20
13	2 400	15	70	15	800	30	50	20
14						20	60	20
15						15	65	20
16	2 400	20	65	15	800	30	50	20
17						20	60	20
18						15	65	20

Intersection design

The designs of the Conventional and unconventional intersections consisted of a four-lane divided major road and a three-lane undivided minor road. Only one four-phase signal was required for the Conventional CORSIM design network shown in Figure 3. However, a total of four two-phase signals had to be modelled on the Superstreet design. Two were placed at the main intersection and two more were placed at the u-turns. The Superstreet intersection was designed to match the configuration as shown in Figure 1. The final Superstreet CORSIM design model

is shown in Figure 4. The circles with the embedded squares (nodes) represent the location of the signals. The additional nodes shown were used to assign turning volumes.

Signalisation

Traffic signal timing is one of the most important tasks in evaluating/comparing the two intersection designs. Since intersections are locations where traffic streams approaching from various directions converge, it is imperative that traffic signals are accurately timed to manage the traffic flow. The green time that each approach has is dependent

upon many factors, with the two main factors being: cycle length and the phase plan. Intersections with large approach volumes and a high percentage of left-turning traffic usually require four phases – one phase for the north and south through traffic, one phase for the east and west through traffic, a phase for the north and south left-turning traffic, and a phase for the east and west left-turning traffic. The cycle length, which is the time taken for one approach to witness a red signal twice, is dependent upon the phase plan, volume, expected loss time for each phase, and pedestrian crossing time. Therefore, the optimum cycle length should be calculated for each case to eliminate as much loss time as possible.

Saturation flow is a key input for optimal signal timing. A small variation in saturation flow values could affect changes in cycle length, thereby affecting the efficiency and operations of an urban system. Many studies have identified suitable saturation flows at signalised intersections as being between 1 500 and 2 500 passenger cars per hour green per lane (pcphgpl). This variation in saturation flow is attributed to site-specific conditions (Williams & Kholslo 2006). The Highway Capacity Manual (HCM 2000) uses a base saturation flow of 1 900 pcphgpl and adjusts for factors such as number of lanes, lane width, grade, lane utilisation, etc.

In this study, a saturation flow of 1 800 vehicles per hour (vph) was used, since the percentage of existing trucks was not considered to be large enough to affect the base conditions.

The desired cycle length and timing were determined using the following equation (HCM 2000):

$$C_{des} = \frac{L}{1 - \frac{V_c}{1\,800 * PHF * \frac{v}{c}}} \quad (1)$$

where:

C_{des} = Desired cycle length

L = Total lost time

V_c = Critical volume

PHF = Peak hour factor

$\frac{v}{c}$ = Volume to Capacity ratio

Although appropriate for most applications, the formula mentioned above fails when the intersection critical (v/c) ratio is equal to or greater than one, and the cycle length estimate becomes unreasonably large or yields a negative number. When cases such as these arose, a cycle length of 120 seconds was used. Furthermore, 120 seconds is a common cycle length for intersections with very high approach volumes.

Developing alternative scenarios

A total of 72 simulation scenarios (36 each per intersection) were developed with various levels of congestion at the intersection. Congestion was created using two sets of traffic volume inputs, which included 1 800 passenger cars per hour (pcph) and 2 400 pcph on the arterial roadway, and 600 pcph and 800 pcph on the collector roadway. Additionally, three different turning percentages were included in the test. As shown in Table 3, each of the two primary scenarios on each major and minor roadway was accompanied by three sets of traffic turning-movement sub-scenarios. The percentage of right-turn volume on the major roadway was fixed at 15%, with varying percentages for the left-turn volume (10%, 15% and 20%). The percentage of right-turn volume on the minor roadway was fixed at 20%, with various percentages for the left-turn volume (30%, 20% and 15%) to consider the effect of the volume for left-turn traffic. Also, it can be seen that each scenario on the major road is accompanied with three different scenarios on the minor roadway. These scenarios were used to represent varying levels of congestion and turning movements at the intersection.

The through lanes on the major road, for both the Conventional and Superstreet design, carry the highest volume. The through movement on the major road was considered to be the most critical and was therefore one of the main entities used for the analysis.

RESULTS

A total of four individual simulation runs, each using different random seed numbers, were executed for each of the 72 scenarios. This resulted in a total test set of 288 simulation runs. The additional simulation runs were also necessary to establish stochasticity within the output so that statistical testing could be carried out. The results reported in this section reflect the average of the comparative measures of effectiveness computed for each of the four replications. Once the simulations are completed, CORSIM creates reports outlining different measures of effectiveness (MOEs). The two performance measures used for the basis of comparison between the Conventional and the Superstreet intersection designs were the network average delay and the average queue length on the through lanes of the major road. These two performance measures were selected because of their direct effect on traffic operations. They also demonstrated the overall efficiency of the intersection design.

Table 4 Conventional and Superstreet delay comparisons (1 800 vph)

Scenario	Network average delay (min)			
	Conventional	Superstreet	Percent reduction	P-value
1	2.22	1.44	35.14%	0.0026
2	2.20	1.47	33.18%	0.001
3	2.30	1.67	27.39%	0.0048
4	10.36	2.24	78.38%	< 0.00001
5	3.42	2.38	30.41%	0.0586
6	3.35	2.09	37.61%	0.0036
7	6.54	1.16	82.26%	0.0028
8	2.37	1.16	51.05%	0.0002
9	2.49	1.31	47.39%	0.0002
10	4.6	2.81	38.91%	0.0036
11	4.42	2.34	47.06%	0.001
12	4.65	2.07	55.48%	0.0004
13	2.66	1.48	44.36%	0.0016
14	2.70	1.26	53.33%	0.0002
15	3.00	2.48	17.33%	0.0942
16	5.20	2.69	48.27%	0.0012
17	4.89	2.56	47.65%	0.0008
18	4.81	2.21	54.05%	0.0006

Table 5 Conventional and Superstreet delay comparisons (2 400 vph)

Scenario	Network average delay (min)			
	Conventional	Superstreet	Percent reduction	P-value
1	7.73	4.28	44.63%	0.0064
2	7.00	4.02	42.57%	0.0026
3	6.52	4.23	35.12%	0.0578
4	11.34	3.87	65.87%	0.0236
5	8.27	3.66	55.74%	0.0016
6	8.41	3.98	52.68%	0.003
7	9.50	4.49	52.74%	0.0269
8	6.91	4.67	32.42%	0.0528
9	7.09	3.22	54.58%	0.0006
10	8.74	4.12	52.86%	0.0052
11	8.75	3.91	55.31%	0.004
12	8.76	3.87	55.82%	0.0036
13	7.24	3.05	57.87%	0.0012
14	7.28	2.86	60.71%	0.0004
15	7.37	3.48	52.78%	0.0014
16	8.86	5.05	43.00%	0.0018
17	8.86	3.91	55.87%	0.0032
18	8.92	4.01	55.04%	0.0044

Average delay

The average delay is a critical operational performance measure on interrupted-flow facilities, which reflects a greater discomfort caused to drivers than travel time (Zhou *et al* 2002). Tables 4 and 5 provide a comparison of the average delay for all scenarios using the Conventional intersection design versus those using the Superstreet intersection design, with major approach volumes of 1 800 vph and

2 400 vph respectively. The tables show the percentage difference/reduction between the Conventional and Superstreet intersection design. The analyses also show the statistical significance of the difference for the network average delay between the Conventional and the Superstreet intersection design. Statistical analyses of the data were performed using the two sample t-tests at 95% confidence level. The t-testing was used to compare relative effectiveness, by

Table 6 Conventional and Superstreet queue length comparisons (1 800 vph)

Scenario	Average queue length (m)			
	Conventional	Superstreet	Percent reduction	P-value
1	12.13	2.63	78.32%	0.0038
2	12.00	2.75	77.08%	0.004
3	4.50	2.63	41.67%	0.042
4	75.63	6.25	91.74%	< 0.00001
5	7.00	5.63	19.57%	0.0926
6	5.75	5.75	0.00%	> 0.9999
7	38.88	1.00	97.43%	< 0.00001
8	3.75	1.00	73.33%	0.001
9	5.00	0.75	85.00%	0.0106
10	18.88	8.88	52.98%	0.0324
11	16.00	6.50	59.38%	0.021
12	19.38	5.38	72.26%	0.0084
13	5.25	1.63	69.05%	0.0126
14	5.63	1.00	82.22%	0.0062
15	7.13	5.25	26.36%	0.2828
16	24.88	7.63	69.35%	0.0092
17	21.25	7.25	65.88%	0.0132
18	18.88	5.88	68.87%	0.0102

Table 7 Conventional and Superstreet queue length comparisons (2 400 vph)

Scenario	Average queue length (m)			
	Conventional	Superstreet	Percent reduction	P-value
1	56.625	13	77.04%	0.0016
2	55.75	12.5	77.58%	0.0018
3	56.375	12.875	77.16%	0.0016
4	87.375	12.25	85.98%	< 0.00001
5	63.125	12.125	80.79%	0.0006
6	64.5	13.25	79.46%	0.0004
7	77.25	16	79.29%	< 0.00001
8	58.125	12	79.35%	0.0012
9	59.75	19.25	67.78%	0.002
10	67.25	13.625	79.74%	0.0002
11	67.25	13.5	79.93%	0.0002
12	66.875	13	80.56%	0.0002
13	59.375	18.5	68.84%	0.0016
14	60.5	17.75	70.66%	0.0015
15	59.5	17.5	70.59%	0.0018
16	67.5	14.875	77.96%	0.0002
17	67.125	12.625	81.19%	0.0002
18	60.5	13	78.51%	< 0.00001

determining if the network average delay on the Superstreet intersection design was shorter than the Conventional intersection design, and the statistical significant difference between the two intersections. The following null and alternative hypotheses were used:

- H_0 : the network average delay on the Conventional and Superstreet intersection design is equal.

- H_1 : the network average delay on the Conventional and Superstreet intersection design differs.

The numbers in italics in the shaded rightmost columns of Tables 4 and 5 show that a significant difference existed between the two intersection designs. It can be seen that the network average delay for almost all scenarios was significantly better using the Superstreet intersection design as opposed

to the Conventional intersection design. The percentage reduction ranged from 27.39% to 82.26%. These results are thought to be due to the additional available green time for the Superstreet intersection design.

Queue length

In the research, queue length was also used as a performance measure of effectiveness for the operational evaluation and comparison of the two intersection designs. Once again, a two-sample t-test was performed at 95% confidence level to determine statistically significant difference in the average queue length between the Conventional and Superstreet intersection designs. The following null and alternative hypotheses were used:

- H_0 : the average queue length on the Conventional and Superstreet intersection design is equal.
- H_1 : the average queue length on the Conventional and Superstreet intersection design differs.

Tables 6 and 7 provide a comparison of the average queue length for all scenarios using the Conventional intersection design versus those using the Superstreet intersection design, with major approach volumes of 1 800 vph and 2 400 vph respectively. The numbers in italics in the shaded rightmost columns of Tables 6 and 7 show that a significant difference existed between the two intersection designs. The tables show that the average queue length for all scenarios was significantly better using the Superstreet intersection design compared to the Conventional intersection design, with a percentage reduction up to 97.43%. Again, these results are thought to be due to the additional available green time for the Superstreet intersection design.

CONCLUSION

The aim of this paper was to evaluate and compare the operational efficiency of a Conventional signalised intersection with an unconventional Superstreet Median Crossover intersection using micro-simulation software. For this purpose two CORSIM models depicting the Superstreet Median Crossover and a Conventional intersection were developed and tested. Several scenarios were created by changing the approach volumes and turning percentages on the major/minor roads to reflect different congestion levels at the intersection, resulting in a total of 72 scenarios, i.e. 36 for each model. The optimal signal timing was calculated for each case to eliminate biasness. Each scenario had its own independent output, and the most pertinent variables were extracted from the output and used in the analysis. The variables considered to be of

primary importance were queue length and average network delay, since these measures directly affect traffic operation on major roads' through lanes.

Among the general findings of this research was the fact that the Superstreet intersection design consistently showed evidence of decreased delay time and queue length when compared to the Conventional design. The percentage reduction in the network delay ranged from 27.39% to 82.26%, and an approximate 97.50% reduction in average network queue length experienced on the through lanes of the major road. Such a large divide is best explained by the signalising methods along the major roads. Generally speaking, increasing green time has positive effects on network delay and queue length. The Superstreet operates on a synchronised two-signal phase, which allows more green time to be allocated to the major roads' through volume, and consequently decreases the chance for queues to form and signal failure to occur. When the major road's through lane volume is relatively high and receives green time priority, this effect is more recognisable.

A more detailed investigation of the comparison data showed that the greatest delay and queue length differences occurred when a high percentage of minor road left-turners (approximately 30%) coincided with a moderate amount of major road left-turners (above 15%). This implies that restricting left turns from minor street approaches could result in operational benefits for intersections in most cases.

Although Superstreet design has been suggested to decrease the overall delay at an intersection, an increased delay is experienced for motorist desiring to travel through and turn left from a minor street approach. For this reason, and because the design of a

Superstreet requires extra right of way, careful consideration concerning the minor street traffic composition and nearby stakeholders should be taken. It is suggested that the Superstreet should be considered only where there is adequate right-of-way and where high arterial through volumes conflict with moderate to low cross-street through volumes. While data presented in this paper provides evidence that the Superstreet is well suited for major street operations, more research is needed to examine the effects of directional volume, lane volume, driver adaptability and expectations in different geometric designs.

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