COMPARISON OF SPUI & TUDI INTERCHANGE ALTERNATIVES WITH COMPUTER SIMULATION MODELING

Matthew J. Selinger, PTOE
William H. Sharp, PTOE

ABSTRACT

There are numerous technical papers and reports discussing the operations of *tight urban diamond interchanges* (TUDIs) and *single-point urban interchanges* (SPUIs). These two interchange types have many similarities and several distinct differences. When comparing the operational differences between the two, the current literature consistently indicates the importance of traffic volumes and other physical intersection characteristics. However, the literature (as a whole) provides conflicting results and recommendations regarding the application of SPUIs and TUDIs. Microscopic computer simulation modeling is an important tool that can help determine a preferred interchange alternative for a specific location.

This technical paper will discuss a microscopic computer simulation workflow developed to compare SPUI and TUDI alternatives. The workflow will detail the use of several well-known traffic engineering programs and provides guidance for proper calibration of the programs when evaluating TUDI and SPUI interchanges. Specific interchange operational issues considered in evaluating the interchanges include interchange geometry, signal phasing, coordination with adjacent signals, saturation flow rates, lost time, clearance intervals, and maximum traffic queues. The paper also presents an example comparison to illustrate the value of microscopic computer simulation analysis when determining a preferred interchange type.

BACKGROUND AND PURPOSE

A preliminary concept study was conducted to determine a preferred interchange alternative for a future arterial roadway intersecting U.S. 20 in Dubuque, Iowa. Based upon right-of-way constraints at the planned interchange site, it was evident that only a TUDI or SPUI would suit the selected interchange location. In order to aid in establishing a preferred interchange alternative, an operational analysis to compare the two alternatives was considered necessary.

Research was conducted to identify methodologies for performing an operational comparison between the TUDI and SPUI alternatives. Several research reports and technical papers have been published on this topic; however, there is a lack of consistency in the findings of these reports regarding which interchange provides better operations based upon a specific set of criteria. Given these findings it was determined that a detailed computer simulation of each interchange concept was necessary to compare the operational characteristics of each. This paper summarizes the workflow developed to analyze the interchanges and discusses the unique characteristics that must be accounted for in the simulation model in order to provide an accurate assessment. For additional comparison between the interchange types, two extra volume scenarios were developed and compared with the same analysis methodology.

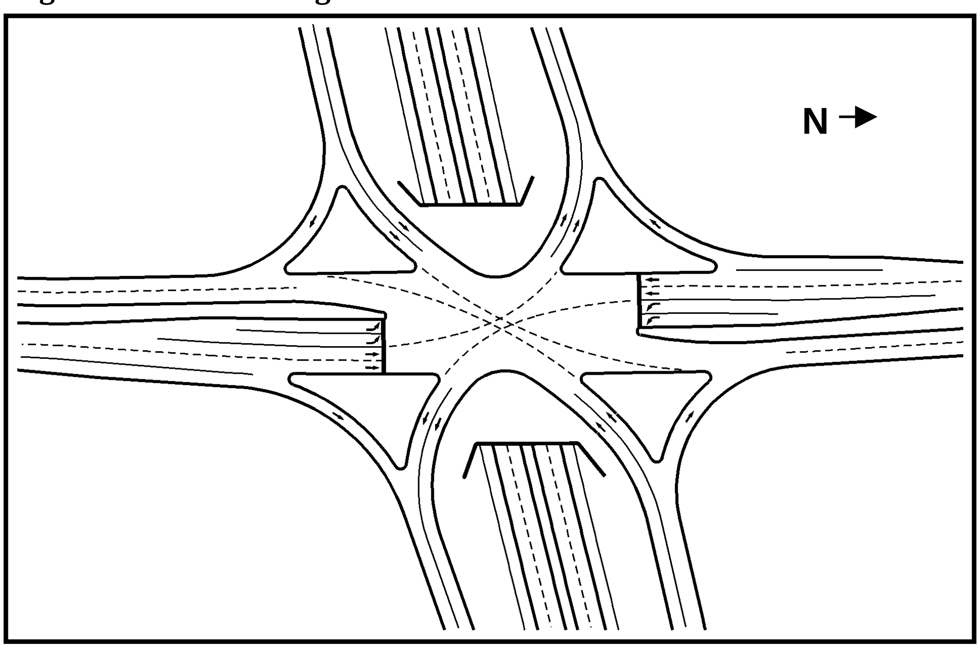
General Interchange Characteristics

The two interchange types have different characteristics relating to capacity, signal phasing, construction cost, structural requirements, and pedestrian considerations. Both interchange types are typically considered in urban areas with limited right-of-way availability. A conceptual layout of the SPUI interchange type is shown in Figure 1.

The SPUI involves a single signalized intersection for ramp and crossroad movements. Due to the substantial width of the intersection, clearance interval (yellow plus all-red) requirements of nine to ten seconds per phase are not uncommon for the SPUI design. Three phase signal control is commonly used for SPUI's, providing leading left-turn and through movement phasing for the cross street and a phase for the ramp left turn movements. The right-turn ramp movements are typically yield controlled.

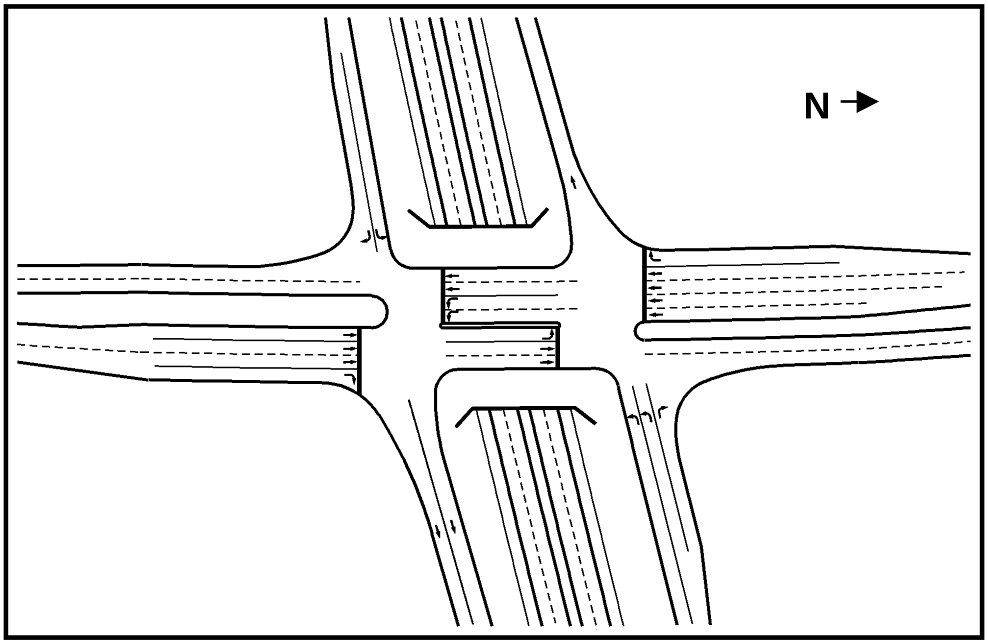
Two and three centered curves are commonly utilized for the horizontal geometry of the ramp left-turn movements to minimize structural requirements. Considerations in the horizontal and vertical geometry of the ramp left-turn movements include sight distance (approaching the signalized intersection) and lateral clearance of the opposing left-turn movements through the intersection.

Figure 1 – SPUI Configuration



A conceptual layout of the TUDI interchange configuration is shown in Figure 2. The TUDI involves two closely spaced signalized intersections to serve ramp terminal and crossroad movements. Typical designs of this type provide 200 feet to 400 feet of separation between the ramp terminal intersections. Due to the close proximity of the signals, the signal operations of the two intersections are operated together as one signal typically with four phase overlap phasing. In many cases, crossroad left-turn storage is provided outside the intersections, and signal timing is developed to minimize the number of vehicles stored between the two signals.

Figure 2 – TUDI Configuration



ANALYSIS PROCEDURES AND WORKFLOW

Unique Operational Analysis Considerations

Many unique characteristics should be considered in the analysis of the different interchange configurations. The timing of the clearance interval should fully consider the lengthy travel paths through the SPUI signalized intersection. The additional phase clearance times result in substantially increased lost time at the intersection. This additional lost time should be considered in optimizing the signal cycle and splits for the intersection. Based upon the operational comparison for near capacity situations, Leisch et al. (1) showed the optimum cycle length for a SPUI is typically ten to thirty percent higher than a TUDI with similar volumes.

Based on field measurements, several studies have shown that the saturation flow rate of the SPUI ramp left-turn movements is significantly higher than the TUDI ramp and typical left-turn movements. Studies have demonstrated a correlation between the SPUI ramp left-turn movement saturation flow rate and the radius of the horizontal alignment of the left-turn movement through the SPUI signalized intersection.

Numerous studies have shown that the presence of frontage roads significantly degrades the capacity of a SPUI. The addition of a fourth phase to serve the frontage road through movements and the additional intersection width results in a substantial increase in intersection lost time and delay. Therefore the TUDI configuration is preferred when the ramp movements are part of a frontage road system.

Pedestrian movements through SPUI's also require detailed study. Pedestrian movements across the crossroad can only be provided as a two step movement (with refuge in the crossroad median) or with the inclusion of an additional phase which significantly impacts overall interchange operations.

The TUDI interchange configuration typically requires specialized traffic signal controllers and signal phasing to ensure coordinated signal operations. Specialized capacity analysis software is also required to efficiently optimize signal phasing and cycle lengths. Due to the minimal spacing between intersections, the capacity analysis approach should fully consider the interaction of the two signals to ensure adequate internal storage is provided.

The location of adjacent traffic signals should be studied carefully with both interchange configurations. Progression opportunities of crossroad through traffic through the TUDI signalized intersections and adjacent signalized intersections can be very difficult due to the complexity of the TUDI signal phasing. Additionally, a closely spaced downstream signal from a SPUI interchange can cause substantial operational problems for the yield controlled right-turn ramp movement, which may impact overall interchange operations.

Analysis Tools

The analysis was conducted with three traffic engineering computer programs; Synchro 4.0, Passer III-98 and CORSIM 4.32. The programs are described as follows:

Synchro 4.0 (Build 221) is a comprehensive network capacity analysis and signal timing software developed by Trafficware. The software is based on the methodology from Chapter 9 of the Highway Capacity Manual and is very user friendly. Synchro can create input files for HCS, Transyt 7F and CORSIM. The software can also import optimized signal timing plans from Transyt 7F. For the concept study, Synchro was utilized to develop portions of the input files for CORSIM for both the SPUI and TUDI alternatives. Additionally, Synchro's signal timing optimization was utilized to develop the SPUI signal timing plans.

PASSER III-98 (Progression Analysis and Signal System Evaluation Routine) is a diamond interchange optimization software developed at the Texas Transportation Institute. The program can evaluate existing or proposed signalization strategies, determine signalization strategies which minimize the average delay per vehicle, and calculate signal timing plans for interconnecting a series of interchanges on one-way frontage roads. The program was utilized to develop the signal timing plans for the TUDI analyses.

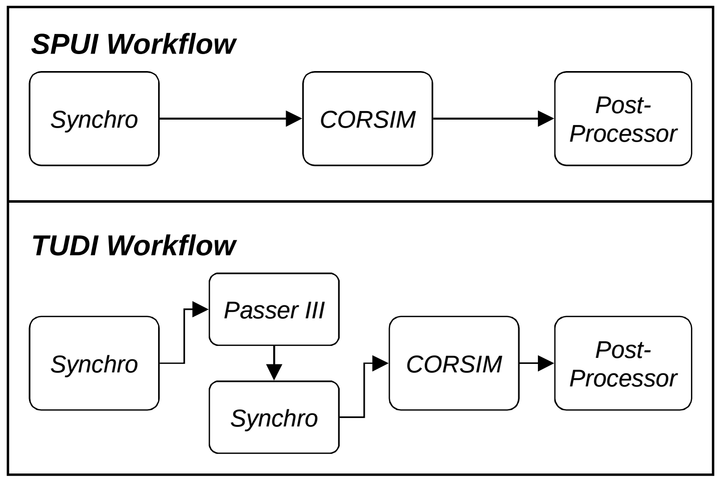
CORSIM was developed by the U.S. Department of Transportation and Federal Highway Administration. The CORSIM model is a time-based, stochastic simulation of individual vehicles in an urban roadway system. Comprehensive measures of effectiveness (MOE's) are collected for each vehicle in the model for every second of model simulation. The MOE's collected by CORSIM include system wide measurements as well as measurements by link. The software also generates animated graphics, which display street networks, traffic control device indications, and the animated movement of vehicles through the model.

Analysis Workflow

SPUI Workflow

The workflow used to evaluate the SPUI interchange was essentially a three-step process as shown in Figure 3. First, the interchange link-node diagram was coded in Synchro to generate an input file for CORSIM. This version of Synchro could not generate a complete CORSIM input file (TRAF file) for an intersection with more than four legs. The SPUI has six legs and Synchro removes two of the legs during the conversion process. Therefore, manual coding of the TRAF file was necessary from this point on. The TRAF file was edited to add the information that was not converted (i.e. redefine lane geometry, lane alignments and turning volumes). Left-turn speeds were adjusted in the TRAF file from the default setting to 25 mph to account for increased left-turn speeds. Start-up lost time and discharge headway can be adjusted based upon the equations provided by Bonneson (2).

Figure 3 – Analysis Flowcharts



The next step was to revisit Synchro and develop an optimum timing plan. The traffic signal was coded as pre-timed to reduce the variability in results that can occur when simulating semi or fully actuated signal control. Also, a cycle length of 90 seconds was selected for both the SPUI and TUDI to reduce the number of variables to consider when comparing results. The pre-timed Synchro phasing and timing plan was manually coded into the TRAF file. Note that it is important to verify that the all-red intervals are coded properly. Once the TRAF file was complete, CORSIM was run and MOE data collected and processed.

TUDI Workflow

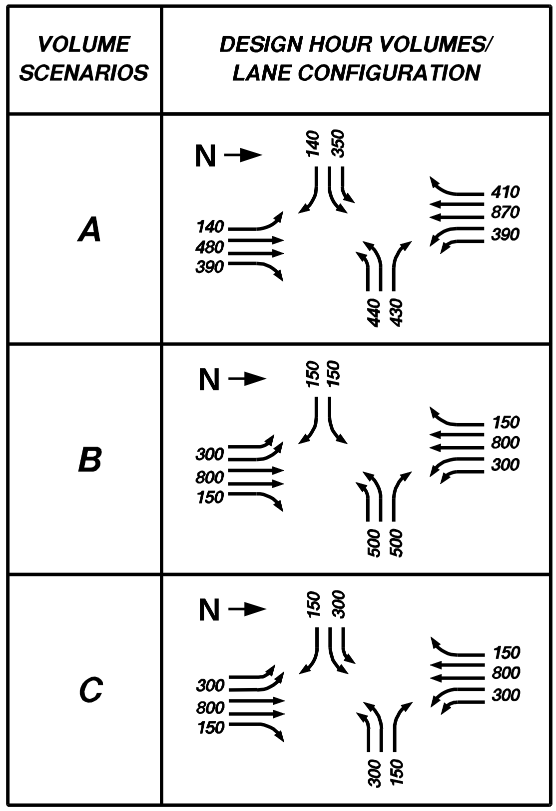
The workflow for the TUDI evaluation utilized Synchro to build the roadway network. Once the roadway network was coded, Passer III was used to develop the signal timing. For the purposes of the TUDI analysis a cycle length of 90 seconds was set, controllers were modeled as pre-timed and lead-lead diamond phasing was designated based upon the client’s common practices. The signal phasing and timing was coded into Synchro being careful to designate phases two and six as the coordinated phases (CORSIM requirement). Synchro was then utilized to generate a TRAF file. CORSIM was run and MOE data collected and processed.

TRAFFIC SIMULATION ANALYSIS

Volume Scenarios

The traffic operations of the SPUI and TUDI were compared for three different volume scenarios. The volume scenarios and the lane configurations for the TUDI are detailed in Figure 4. Due to the difficulty of expanding the SPUI and the uncertainty associated with the traffic projections, dual left turn movements were assumed for the ramp and cross street movements for all volume scenarios for the SPUI configuration. Many of the left-turn movements do not warrant dual left turn lanes solely based on the design year peak hour volumes shown. Volume scenario 'A' represents real world traffic projections from the U.S. 20 Concept Study. To compare the capacity and delay characteristics of the SPUI and TUDI, the traffic patterns were varied in volume scenario 'B' and 'C'. Volume scenario 'B' included unbalanced ramp left-turn movements, and volume scenario 'C' included completely balanced ramp and cross street movements.

Figure 4 – Volume Scenarios



Findings

The traffic simulation analysis resulted in numerous traffic measures of effectiveness for the interchange configurations and volume scenarios noted above. The intersection average vehicle control delay, level of service, and queue lengths are summarized in Table 1 and Table 2 for the SPUI and TUDI interchange configurations, respectively. Queue lengths included in the table represent the maximum simulated queue lengths on the ramp and crossroad.

Table 1 – SPUI Intersection Measures of Effectiveness

Volume Scenario	Average Vehicle Delay (sec/veh)	Level of Service	Queue Lengths (ft)	
			Ramp	Crossroad
A	19.1	B	280	440
B	23.2	C	300	420
C	20.9	C	180	420

The intersection measures of effectiveness are very comparable for the different interchange configurations. As noted earlier in the study, specialized signal phasing is required for the TUDI interchange configuration to ensure progression of the left-turn ramp movements and cross-street through movements are coordinated through both traffic signals. For the volume scenarios analyzed, the cross street queue lengths tended to be higher for the TUDI interchange.

Table 2 – TUDI Intersection Measures of Effectiveness

Volume Scenario	Average Vehicle Delay (sec/veh)	Level of Service	Queue Lengths (ft)	
			Ramp	Crossroad
A – North	18.8	B	260	440
A – South	10.5	B	180	260
B – North	19.4	B	260	540
B – South	13.6	B	160	400
C – North	16.1	B	180	560
C – South	16.4	B	160	580

COMPARITIVE ASSESSMENT AND CONCLUSIONS

Based on the traffic simulation analysis, system-wide measures of effectiveness were calculated to enable direct comparative assessment of the interchange alternatives. Table 3 summarizes the system-wide stop delay and stop percentages. Operations for both interchange configurations are well within typically desired design criteria. For the volume scenarios studied, stop delay and stop percentages were minimized with the SPUI interchange configuration. It should be noted that higher capacity was anticipated for the SPUI for volume scenarios ‘A’ and ‘B’ due to the additional left-turn lanes provided with the SPUI. For volume scenario ‘C’, the simulated stop percentage was over 100% for the TUDI interchange, indicating some vehicles were stopped at both signalized intersections.

Table 3 – System-Wide Measures of Effectiveness Comparison

Volume Scenario	Total Stop Delay (veh min / hr)		Average Stop Delay (sec / veh)		Stop Percentage	
	TUDI	SPUI	TUDI	SPUI	TUDI	SPUI
A	1154	998	17.2	14.8	79%	71%
B	1254	1149	19.8	18.1	98%	73%
C	1094	921	19.3	16.2	115%	70%

The results of the operational analysis are one component to consider in interchange type selection. In the case of the volumes scenarios studied, the additional construction costs of the SPUI would need to be carefully weighed with the operational benefits gained. Additional considerations should include engineering experience and judgement as well as site specific considerations including right-of-way impacts, pedestrian accommodations, and intersection sight distance.

RECOMMENDATIONS FOR FURTHER STUDY

- Conduct traffic simulation to compare the operational characteristics for the TUDI and SPUI interchange configurations for a wider range of volume scenarios, particularly in situations approaching capacity with unbalanced crossroad through or ramp left-turn traffic volumes.
- Utilize traffic simulation to evaluate the operations of the TUDI and SPUI interchange configurations considering the effects of adjacent signalized intersection locations.
- Provide more research into operational and safety characteristics of existing TUDI and SPUI interchange locations.

REFERENCES

1. Leisch, Joel P., Thomas Urbanik II, and James P. Oxley. A Comparison of Two Diamond Interchange Forms in Urban Areas. *ITE Journal*, November 1989.
2. Bonneson, J. A. Study of Headway and Lost Time at Single-Point Urban Interchanges. *Transportation Research Record 1365*, TRB, National Research Council, Washington, DC., 1992.
3. Messer, C.J., J. A. Bonneson, S. D. Anderson, and W. F. McFarland. *NCHRP Report 345: Single Point Urban Interchange Design and Operations Analysis*. TRB, National Research Council, Washington, D.C., December 1991.
4. Fowler, Brian C., An Operational Comparison of the Single-Point Urban and Tight-Diamond Interchanges. *ITE Journal*, April 1993.
5. Highway Capacity Manual, Special Report 209, Third Edition, Transportation Research Board, Washington, DC, Updated 1997.
6. A Policy on Geometric Design of Highways and Streets, American Association of State Highways and Transportation Officials, Washington, DC, 1994.
7. Traffic Models Overview Handbook, Report No. FHWA-SA-93-050, Federal Highway Administration, Washington, DC, 1993.
8. PASSER III-98 User Guide (on-line), Developed by Texas Transportation Institute of the Texas A&M University System.
9. CORSIM User Guide (on-line), Developed by ITT Industries for FHWA Office of Operations Research, Development and Technology.
10. Synchro 4.0 User Guide (on-line), Developed by Trafficware Corporation, 1009B Solano Ave, Albany, CA.

MATTHEW J. SELINGER

Matthew J. Selinger, PE, PTOE, is a Transportation Engineer for HDR Engineering, Inc. in Omaha, NE, USA. He received his BS in civil engineering from the University of Nebraska – Lincoln. Selinger is a Member of ITE.

WILLIAM H. SHARP

William H. Sharp, PE, PTOE, is a Senior Transportation Engineer for HDR Engineering, Inc. in Omaha, NE, USA. He received his BS and MS degrees in civil engineering from the University of Nebraska – Lincoln. Sharp is an Associate of ITE.