The Split Intersection

A Solution for a Congested Intersection

JOE G. BARED
Federal Highway Administration
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296
joe.bared@fhwa.dot.gov
EVANGELOS I. KAISAR
Department of Civil and Environmental Engineering
University of Maryland
College Park, MD 20742
kaisar@wam.umd.edu

ABSTRACT

A proposed innovative treatment for congested urban and suburban intersections is the split intersection. It facilitates a smoother flow with less driver delay by reducing the number of signal phases. The success of converting to the split intersection is analyzed by using microsimulation to predicate previous claims and provide guidance.

INTRODUCTION AND APPLICATION

In recent years, drivers have faced recurring congestion problems, mainly at intersections. Intersections present (by their nature) focal bottlenecks and vast conflict areas. With full access control, the capacity of an interchange is more than double that of an at-grade intersection. Around the world, various alternatives, other than conventional treatments, are being considered to solve congestion problems at intersections. For some conditions here in the United States, we can improve the level of service at intersections with the application of the split intersection.

The split intersection (SPI) is currently an uncommon solution to a busy intersection. It separates traffic flow on the mainline into offset one-way roads (Figures 1 and 2). This layout is comparable to a diamond at-grade interchange without bypassing through traffic. By separating the mainline traffic flow, substantial delays are reduced and a few potential conflicts are eliminated. When the two signals are timed correctly (preferably by a single controller), the separation facilitates smooth and less interrupted flows at higher volumes. Most of the savings in delay are derived from eliminating one phase out of four from the single intersection. Effective green time is therefore added to the cycle for left-turning vehicles by reducing initial perception-reaction time, startup time, and all red.

Major disadvantages cited by Hakkert and BenYakov, and Polus and Cohen, are: (1) the high initial cost of construction and right-of-way purchases, (2) the need to stop at

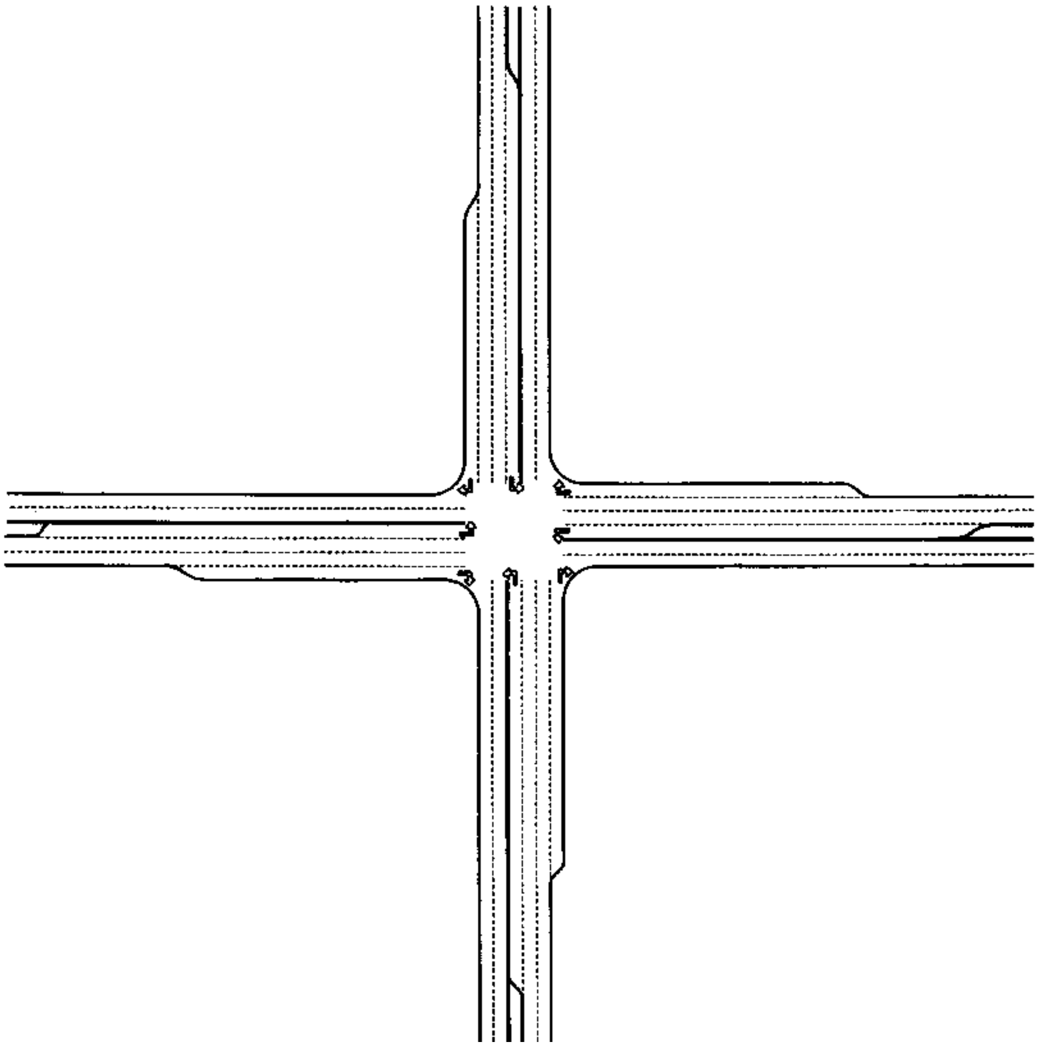


FIGURE 1 Typical single intersection.

two intersections instead of one when the two signals are not well coordinated, and (3) the possible wrong-way movements by unfamiliar drivers.

Advantages of split intersections are documented by Polus and Cohen, showing an increase in capacity and a savings in delay. Figure 3 illustrates a constant increase in through capacity for the split when left-turning volumes rise, because the increasing left-turning volume requires more green time. For a cycle length of 120 seconds and at the highest level of turning volumes, capacity is about 35 percent higher then for a single intersection.

Figure 4 shows a very high savings in delay as a function of the through volume. Although a saving of 700 seconds per vehicle of stop delay seems to be very high, the assumptions used are not completely stated to evaluate the validity of these results.

Finally, a split intersection separates potential conflict points and slightly reduces their number compared with the traditional four-legged intersection (Figure 5).

The split intersection is primarily considered in isolated, busy suburban intersections expected to experience traffic growth with particularly high left-turning

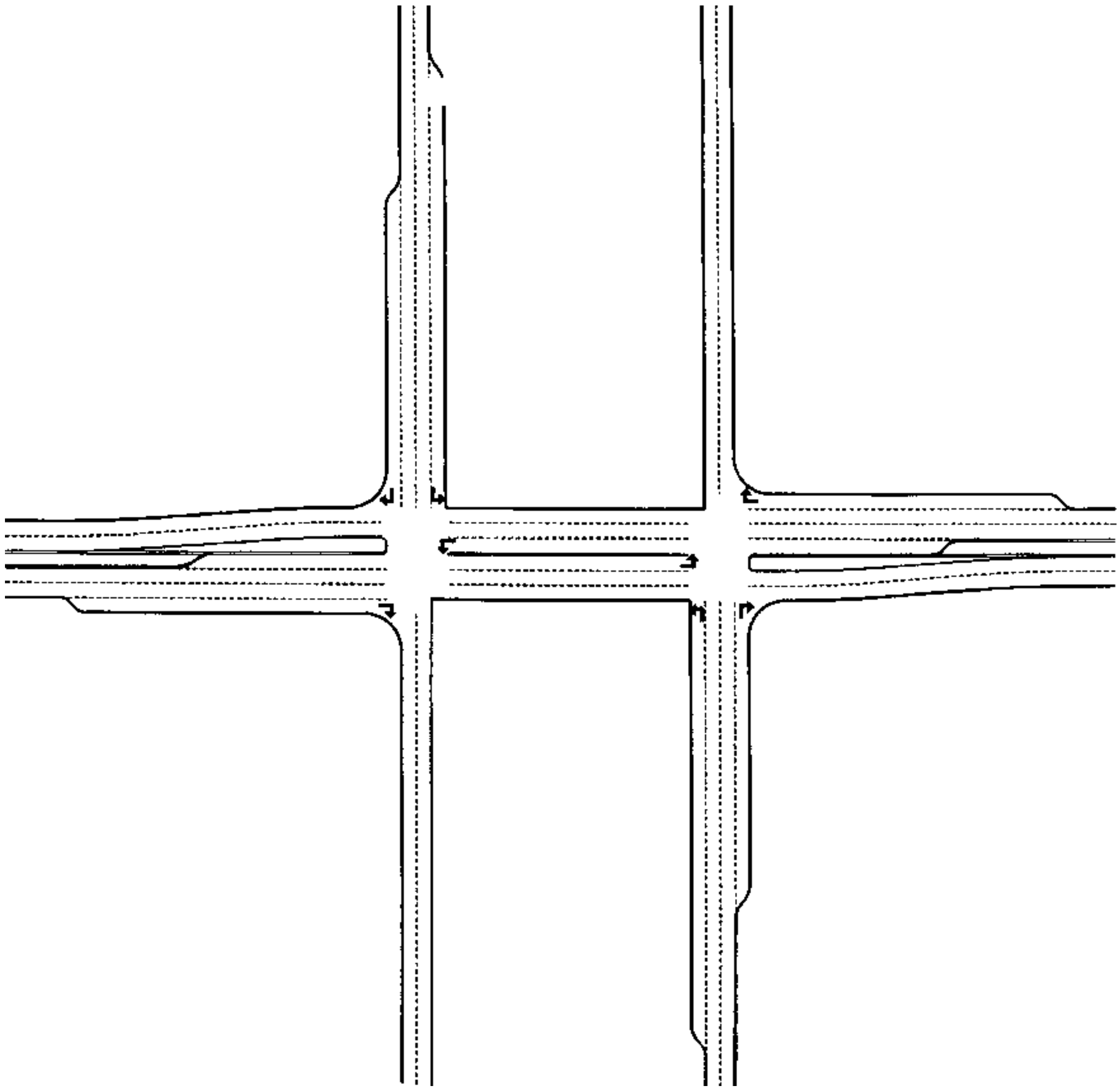


FIGURE 2 Typical split intersection.

volumes. It could be considered as a transition to the grade-separated diamond interchange (Hakkert and BenYakov, 1978) before building the bridge for the through roadway (Figure 6).

A busy suburban intersection in Tel Aviv, Israel, was converted to a split intersection in 1975. According to Hakkert and BenYakov (1978), the economic benefits have been proven by the savings in delay and the postponement of the construction of a complete grade-separated interchange. Delay calculations showed noticeable savings for the split intersection compared to single intersection (Table 1). According to anecdotal accounts, other split intersections were constructed in Israel and were since converted to diamond grade-separated interchanges.

Another application of the split intersection is possible in urban areas, where two-way streets can be converted to one way if the offset between the two streets is adequate.

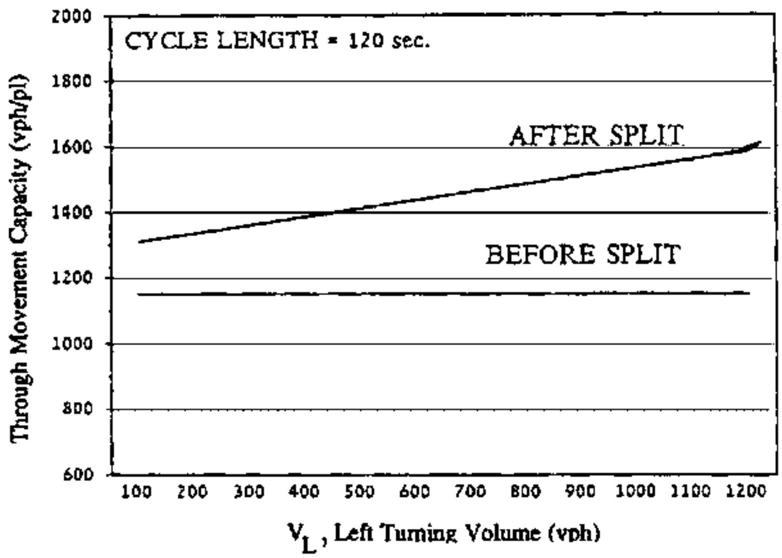


FIGURE 3 Increase in capacity of through movement after split (Polus).

This paper will complement previous findings by conducting a delay comparison between single and split intersections using a traffic microsimulation model [CORSIM (CORridor SIMulation)] to provide guidance on the benefits of conversion.

ANALYSIS METHODOLOGY

Single and split intersections are modeled in CORSIM, with identical geometric dimensions in the length of the approaches and turning lanes (right and left turns), and the number of through lanes. The first simulated case is for a four-lane major highway (north-south) with a 40-mi/h posted speed intersecting a four-lane minor or major highway with a 45-mi/h

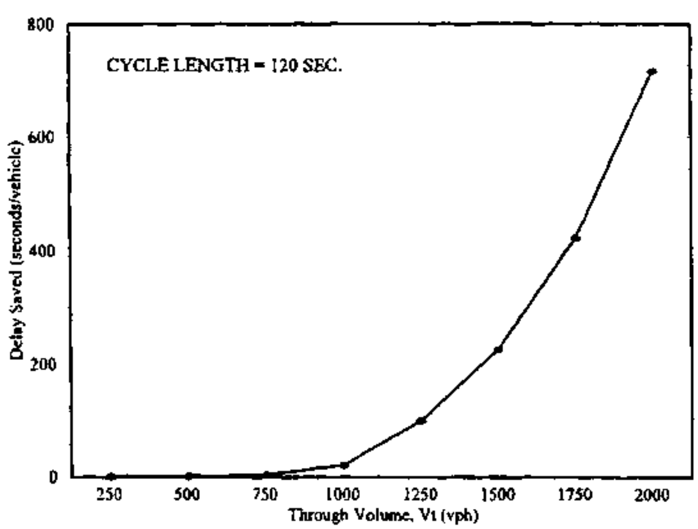
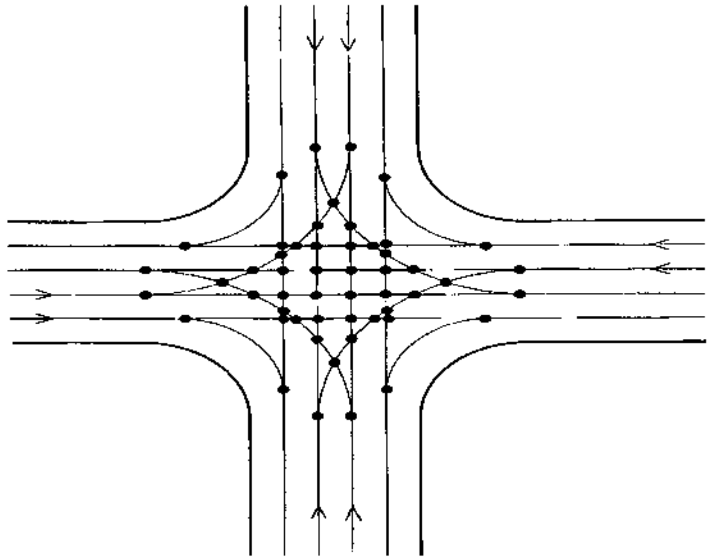


FIGURE 4 Delay saved for through movement after split (Polus).

(a)



(b)

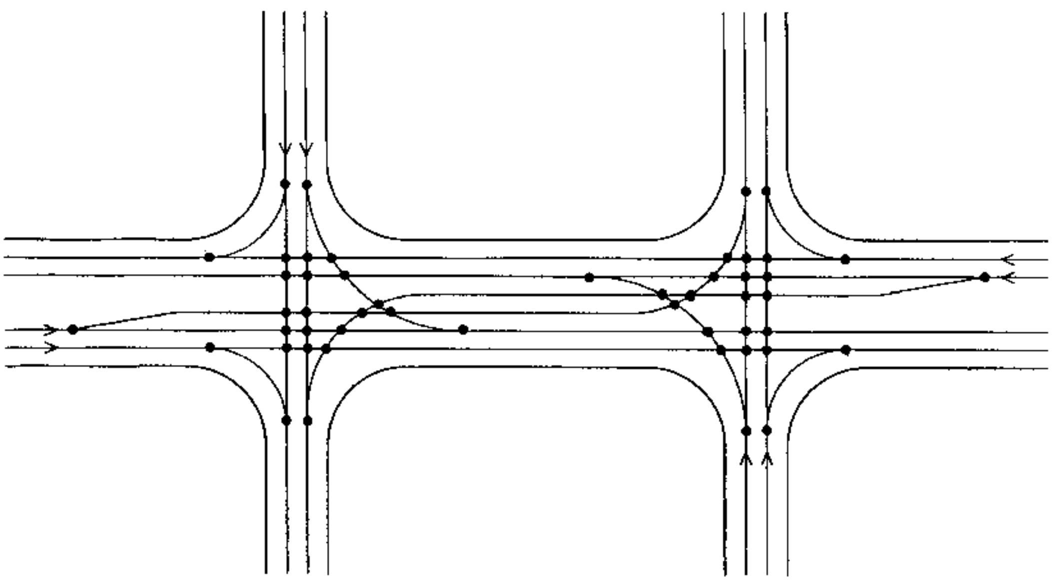


FIGURE 5 Potential conflict points for (a) single (52 points) and (b) split intersections (50 points).

posted speed. A constant left-turning percentage of 15 percent is assumed on all four approaches. For the split intersection, an offset of 200 feet is provided between the two separated intersections from the stop bar to the following stop bar. Various scenarios of entering volumes on all approaches are selected to cover many possible flow conditions (e.g., equal flows on all approaches and unbalanced flows). At each approach, the left-turn lane length is 350 feet. The second simulated case is similar to the first, with the exception of assigning 30 percent left-turning volumes on all four approaches, with an offset of 300 feet

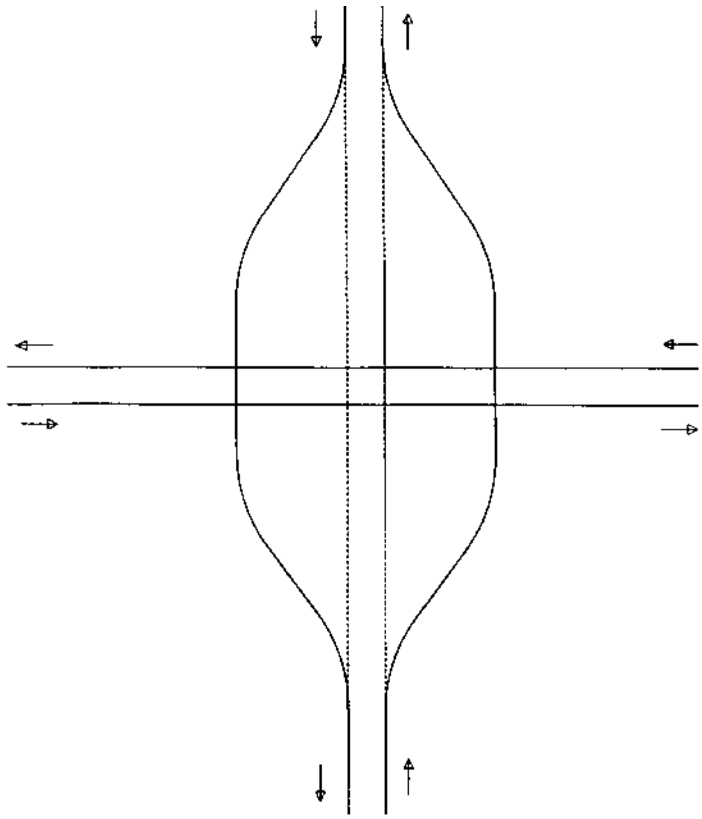


FIGURE 6 Typical layout of a conversion to a split intersection.

for the split intersection. For the second case, each approach is designed with dual left-turn lanes that are 450 feet long. Both cases are assigned 10 percent right-turning traffic with 250-foot right-turn lanes. Moreover, both cases are modeled with 5 percent truck traffic on all approaches.

Although signal timing (cycle length and phase split) is not the objective of this paper, it is necessary to determine an optimum signalization plan to evaluate the effectiveness of intersection configuration. For a single intersection, PASSER II is used to help determine the best signal timing for cycle lengths ranging from 60 to 120 seconds, with 10-second increments. When undersaturated conditions are analyzed, the run with the smallest delay is selected for cycle length and phase timing. In saturated/oversaturated conditions, PASSER II does not compute accurate delays. Nevertheless, phase timing is still

TABLE 1 Calculated Total Delay (Vehicle-Hours/Hour)

	Single Intersection	Split Intersection	Savings in Delay
Morning peak hour	140	62	55%
Afternoon peak hour	60	38	37%
Off-peak hour	31	21	33%

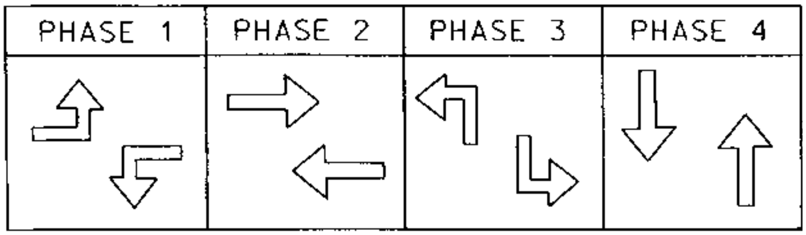


FIGURE 7 Typical phasing for single intersections.

reliable. When various cycle lengths are applied in CORSIM for saturated/oversaturated conditions, longer cycle durations yield a lower delay for single intersections. The four-phase arrangement used in modeling is shown in Figure 7 with exclusive left-turns and no overlap.

For the split intersection, PASSER III is used to help determine cycle length (ranging from 60 to 120 seconds), optimum phase timing, and time offset between the two signals. PASSER III minimizes intersection delay for undersaturated conditions only, similar to PASSER II. Nevertheless, phase timing and offset are reliable in saturated/oversaturated conditions. Conversely, for saturated/oversaturated conditions, shorter cycle lengths provided lower delays according to CORSIM. The split intersection is controlled by three-phase signals that are coordinated according to five sequences shown in Figure 8. A best left-turn sequence or phase order is provided by PASSER III in conjunction with the interval offset. Both programs use deterministic approaches in analyzing and optimizing signal timing without accounting accurately for individual vehicle performance (e.g., acceleration/deceleration, lane changing). Therefore, the desired signal timing could possibly be slightly improved.

Then, for each scenario of traffic flow, pertinent data from the two PASSER programs are separately input into CORSIM to model the single and split intersections (for 15 minutes). Results are verified and recorded for each scenario using various cycle lengths.

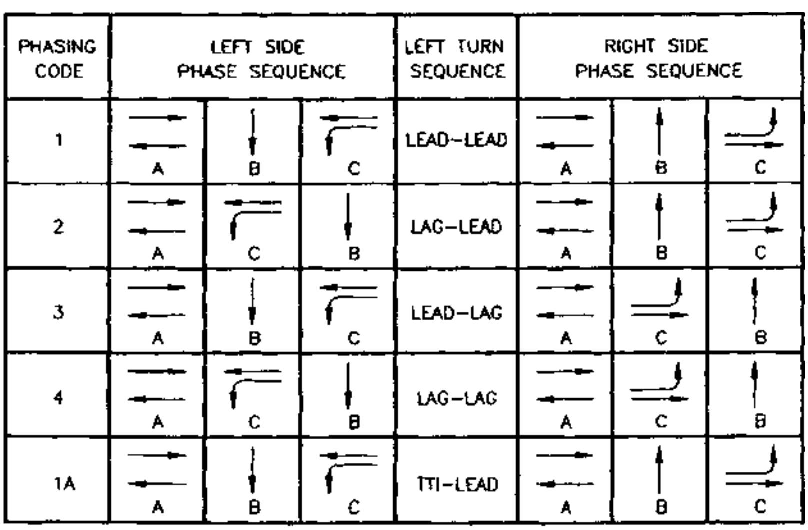


FIGURE 8 Phasing types available in PASSER III to optimize delay.

Although CORSIM is capable of modeling oversaturated traffic conditions, a peculiar behavior is noted at very high flows with 30 percent left-turning traffic. At the latter part of the simulation period, a gridlock develops, preventing left-turning traffic within the offset highway section from moving because of a spill back into both intersections. In practice, this could be prevented by stopping the vehicles on red when the offset section is saturated, and by designing a little longer offset when growth is anticipated. The most significant variables affecting delay are the length of the offset section and signal coordination for the split intersection, and the length of left-turn lanes for both types of intersections.

CORSIM provides comprehensive capabilities, including traffic operational analysis, geometric design/traffic operational evaluation, and assessment of mitigation strategies under congested conditions. PASSER II-90 is a program developed by the Texas Transportation Institute (TTI) to evaluate and determine optimum signalization strategies for an arterial signal system to reduce delays, stops, and fuel consumption. It is equally capable of analyzing single, isolated intersections. PASSER III-90 is also a program developed by TTI to evaluate existing or proposed signalization strategies for diamond interchanges and to determine strategies that minimize the average delay per vehicle.

RESULTS

The results of the CORSIM analysis show that travel delay savings increase for the split intersection as entering and left-turning volumes rise (Figures 9 and 10). As stated earlier, the savings in delay are derived from eliminating one phase for the split intersection, thus increasing the percentage of effective green time. Although at higher volumes the optimum cycle length for the split intersection was shorter than for the single intersection, the additional proportion of effective green yielded significant delay savings where through and left-turning traffic move concurrently. An exponential form from Microsoft

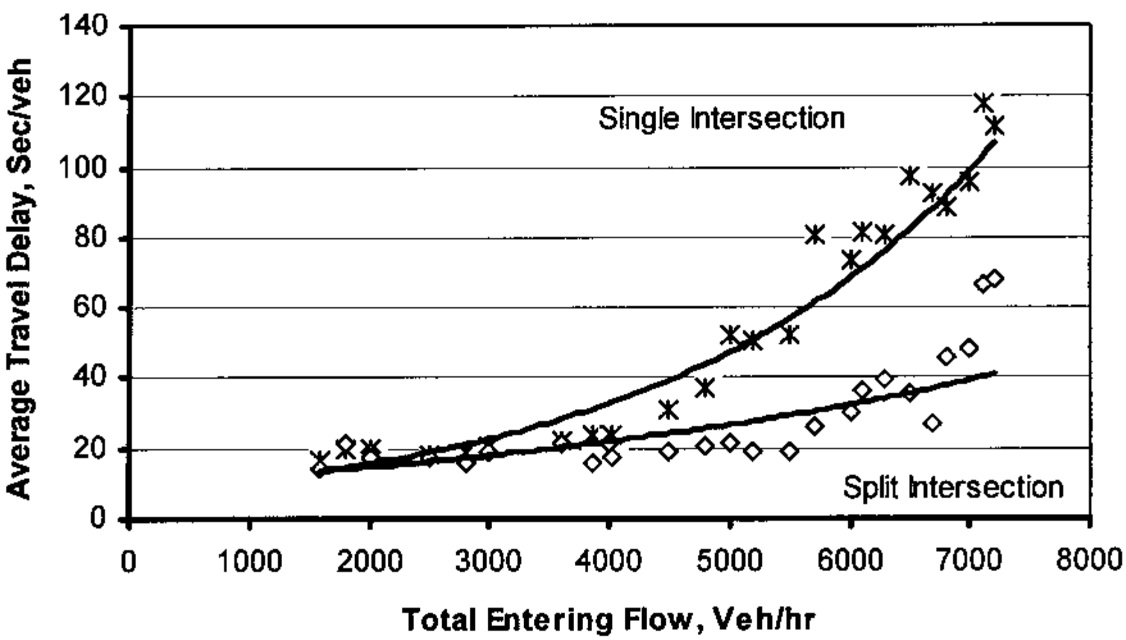


FIGURE 9 Travel delay versus entering flow for single and split intersections with 15 percent left turning flow.

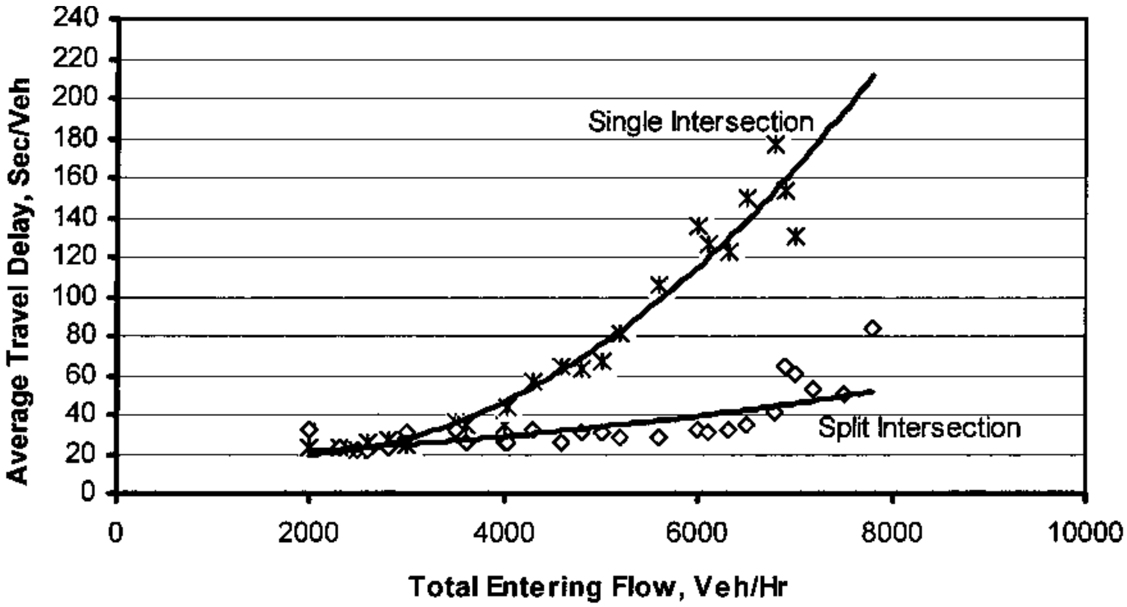


FIGURE 10 Travel delay versus entering flow for single and split intersections with 30 percent left-turning flow.

Excel is selected to fit the scatter of the CORSIM data. This displays an approximation of the model performance. No statistical analysis was conducted to determine a best model or an evaluation of goodness-of-fit. A visual evaluation of Figures 9 and 10 shows reasonable fit for most points below 7,000 vehicles per hour (vph).

Figures 9 and 10 reveal gradual, then noticeable, savings in travel delay for the split intersection starting at total entering flows of 4,000 vph. Average delays for single and split intersections are comparable between 1,600 vph (smallest simulated flow) and 4,000 vph. In comparison to computed delays shown in table 1, these simulated results yield approximately a 40 to 50 percent savings in travel delay at higher volumes (5,000 to 6,000 vph total entering flows) with 15 percent left-turning traffic. For 30 percent left-turning traffic, the savings in delay range from 50 to 60 percent for the same range of total entering flows.

A simple economic analysis provides very encouraging documentation of substantial benefits when converting to the split intersection. The computed results in Table 2 show the extent of savings per year in vehicle-hours and in equivalent costs for two selected peak flows. The assumptions used in the computations are as follows:

TABLE 2 Savings in Delay in Time and Cost for Two Peak Volumes

Peak volume (vph)	15% left-turning flow			30% left-turning flow		
	Average delay savings (sec/veh)	Total delay savings per year (veh-h)	Cost savings ($/yr)	Delay savings (sec/veh)	Total delay savings per year (veh-h)	Cost savings ($/yr)
5,000	20	44,400	564,000	40	88,900	1,129,000
6,000	35	93,300	1,185,000	70	186,700	2,371,000

- Four hours of peak periods per day (h).
- Peak period occurs over 250 working days per year.
- Nationwide average occupancy factor of 1.6 passengers per vehicle (p).
- Recommended hourly value of travel-time savings per person-hour of $12.70 ($c$).

This value is given in an FHWA memorandum (April 1997) on departmental guidance for conducting economic evaluations. It has been adjusted from 1995 to 1998 dollars using the consumer price index.

$$C = (q)(h)(250)(d/3600)(p)(c)$$

where:

C = Estimated annual total cost ($/year).
q = Peak volume (vph).
d = Average savings in delay (seconds/veh).

Table 3 provides estimated savings of annual fuel consumption for the 15 and 30 percent left-turning proportion at the given peak flows.

CONCLUSIONS AND RECOMMENDATIONS

General observations and recommendations are as follows:

- Split intersections are best suited to alleviate traffic congestion of single intersections in isolated suburban areas where the total approaching volume is greater than 4,000 vph. They can possibly be used along an arterial with progression when the arterial timing is compatible with the optimum signal timing of the split intersection. Moreover, their application is feasible in urban areas when streets are converted to one-way traffic with adequate available offset.
- As illustrated in Figures 9 and 10 and Table 2, higher volumes and higher left-turning traffic yield substantial economic benefits for split intersections. These benefits could easily justify the conversion of a split intersection over its economic life, or as a transition to a grade-separated diamond interchange in the future.
- Although the cost of construction of the split intersection could be prohibitive when right-of-way is constrained, this new configuration might still be an economical alternative.
- The length of the split intersection offset, and the number and length of left-turn lanes in conjunction with well-coordinated signals are crucial to a smooth and economical operation that yields the derived savings.

TABLE 3 Savings in Fuel Consumption for Two Peak Volumes

Peak volume (vph)	Fuel saving (gallons/year)	
	15% left-turning flow	30% left-turning flow
5,000	280	21,120
6,000	18,100	33,000

- A well-designed and coordinated signal timing should rely on accurate estimation and forecasts of flows on all approaches of the split intersection.
- In the case of highly oversaturated conditions, spill back of left-turning traffic along the east-west highway blocking the intersections could be prevented by controlling left-turning traffic on the crossroad.
- Although this study applies only to fixed signal timing, actuated timing could provide smooth and efficient operation during off-peak flow. More analysis is needed to investigate actuated signal timing for various scenarios. Additional research is also needed to evaluate the effectiveness of the split intersection along an arterial progression.
- For specific applications, it is recommended that a detailed comparison process similar to this study be applied rather than simply relying on the derived fitted comparison of Figures 9 and 10.
- Ideally, a field study is recommended to validate the simulated findings. However, this is unlikely because (according to the literature) very few intersections have been converted to two split intersections in Israel with noted success. Besides the two case conditions in this paper, other cases could similarly be simulated in CORSIM with differing traffic volume and roadway cross-section scenarios.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). *A Policy of Geometric Design of Highways and Streets*, Washington, D.C., 1994.

Federal Highway Administration. *PASSER II-90, User's Guide, Methodology for Optimizing Signal Timing: M|O|S|T, Volume 3,* 1991.

Federal Highway Administration. *Traffic Software Integrated System (TSIS) User's Guide*, Version 4.02, 1998.

Hakkert, S., and Y. BenYakov. Single-Level Interchange or Splitting a Signalized Intersection. *Traffic Engineering and Control*, Aug./Sept. 1978.

Polus, A., and R. Cohen. Operational Impact of Split Intersections. In *Transportation Research Record* 1579, TRB, National Research Council, Washington, D.C., 1997, pp. 73–78.

Texas Transportation Institute. *PASSER III-90, User's Manual and Application Guide*. Texas A&M University, College Station, 1991.

Special Report 209: *Highway Capacity Manual* (1997 update). TRB, National Research Council, Washington, D.C., 1998.