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ADVANTAGES OF THE SPLIT INTERSECTION

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As urban and suburban intersections become more congested, a possible remedy to the recurring traffic jam is to separate the grades of the intersecting roads in the form of a diamond interchanges. A more economical intersection treatment is the split intersection. This treatment requires that the major road be separated into two one-way roads comparable to an at-grade diamond junction. The split intersection facilitates smoother traffic flows with less delay, and safety should be improved by reducing congestion and separating the opposing directions of traffic.

Background and Application

Intersections, by their nature, easily become traffic bottlenecks and conflict areas, but the capacity of an interchange with full access control is more than twice that of an at-grade intersection.

For some conditions in the United States, the level of service at intersections can be improved by applying a split intersection. It is applicable as a permanent treatment or as a transitional phase before the construction of a grade-separated diamond interchange, when required by heavy traffic.

The split intersection is currently an uncommon solution to a busy intersection. It separates traffic flow on the mainline into offset one-way roads. (See figures 1 and 2.) This layout is comparable to a diamond at-grade interchange without the 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 smoother and less interrupted flows at higher volumes. Most of the reduction in delay is derived from eliminating one of the

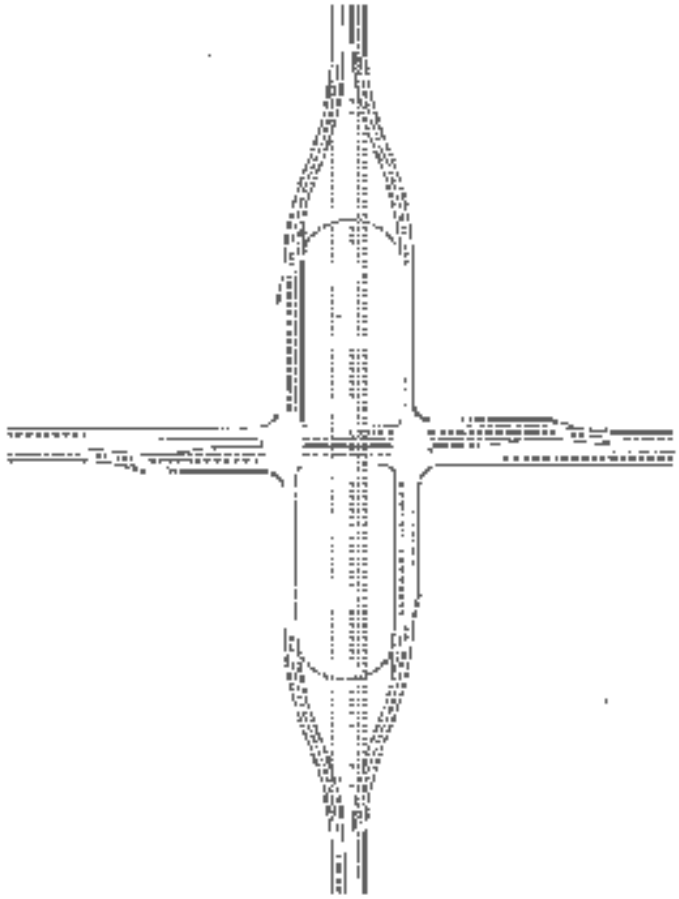

Figure 2 - Typical split intersection (with possible median U-turn).

four traffic-signal phases of the single intersection. Effectively, this adds more "green time" to the cycle for left-turning vehicles by reducing initial perception reaction time, startup time, and all "red time."

The three major disadvantages of a split intersection, as cited by Hakkert and Ben Yakov and by Polus and Cohen, are the high initial cost of construction and of right-of-way purchases, the likelihood of stopping at two intersections instead of one when the two signals are not well-coordinated, and the possible wrong-way movements by unfamiliar drivers.1,2

Polus and Cohen document the advantages of split intersections, showing an increase in capacity and a reduction 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 volume, capacity is about 35 percent higher than for a single intersection.

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

A split intersection separates potential conflict points and slightly reduces their locations compared with the traditional four-legged intersection.3 (See figure 5.) Hakkert and Mahalel derived a regression equation relating accidents to conflict points. The equation explains 60 percent of the variation, which is more than most accident prediction models that relate accidents to highway factors.

It is possible that the separation of conflicts combined with a reduction in the number of signal phases will have a positive safety effect. At every transition between phases, drivers are more likely to violate the traffic signal than they would during a steady stream of trafffic when the light is green. More research is necessary in this area or in the area of surrogate or exposure safety measures in traffic microsimulation.

The split intersection is primarily considered in an isolated and congested suburban intersection expected to experience traffic growth with particularly high left-turning

volumes. It could be considered as a transition to a grade-separated diamond interchange with a bridge on the through roadway.1 Access management may be reduced within the wider boundaries of this special treatment.

Further treatment is possible by providing U-turns for the left-turning vehicles to reduce the number of signal phases to two. This treatment will eliminate the need for storage on the cross-street. Nevertheless, high left-turning traffic will face other conflicts when crossing through lanes on the major highway.

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

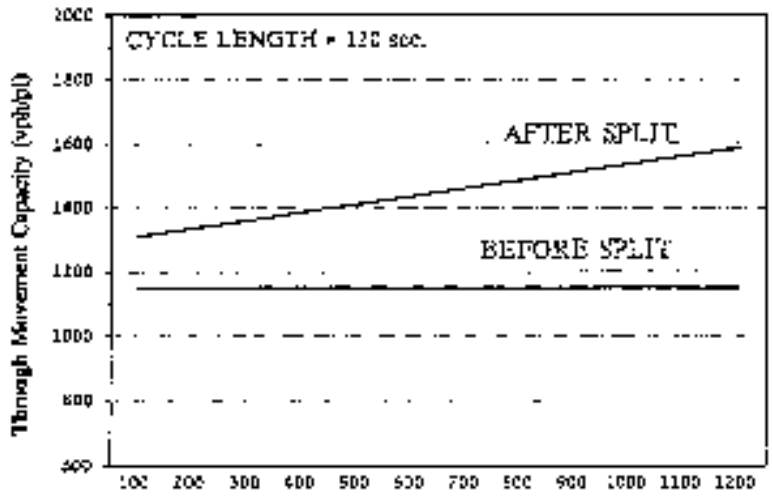

Figure 3 - Increase in capacity of through movement after split. (Polus)

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

The authors of this article conducted a delay comparison between single and split intersections using a traffic microsimulation model - CORSIM (CORridor SIMulation) - to provide insight into the benefits of conversion.

Analysis Methodology

Single and split intersections are modeled in CORSIM Version 4.3 with identical geometric dimensions for the length of the approaches and turning lanes (right and left turns) and the same number of through lanes.

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 optimal 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.

The first simulated case is for a four-lane major highway (north-south) with a 40-mile per hour (64-kilometer per hour) posted speed intersecting a four-lane highway with a 45-mi/h (72-km/h) posted speed. A constant left-turning percentage of 15 percent is assumed on all four approaches. The split intersection has an offset of 200 feet (61 meters) between the two separated intersections. The researchers selected various scenarios of entering volumes on all approaches to cover many possible flow conditions (e.g., equal flows on all approaches and some imbalanced flows). More scenarios with imbalanced flows might necessitate a longer offset than the modeled distances of 200 feet (61 meters) and 300 feet (91 meters). At each approach, the length of the left-turn lane is 350 feet (107 meters).

The second simulated case is similar to the first, but it assumes a 30-percent left-turning volume on all four approaches and the split intersection is offset by 300 feet (91 meters). For the second case, each approach is designed with dual left-turn lanes that are 450 feet (137 meters) long. Both cases are assigned 10-percent right-turning traffic with 250-foot (76-meter) 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 research, it is necessary to determine an optimal signal plan to evaluate the effectiveness of the 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.4 Nevertheless, phase timing is still 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 6 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 shorter delays according to CORSIM. The split intersection is controlled by three-phase signals that are coordinated according to five sequences. 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.5

Then, for each traffic flow scenario, 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.

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, gridlock develops, preventing left-turning traffic within the offset highway section from moving because of a spill-back into both intersections.6 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, the signal coordination for the split intersection, and the length of the left-turn lanes for both types of intersections.

Results

The CORSIM analyses show that the split intersection accommodates higher volumes of traffic with less delay per vehicle than the single intersection. The delay differential between the two types of intersections increases as entering and left-turning volumes rise. (See figures 7 and 8.) As stated earlier, the reductions 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 optimal cycle length for the split intersection was shorter than for the single intersection, the additional proportion of effective green time yielded significant delay reductions when through and left-turning traffic move concurrently.

An exponential form from Microsoft 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 of the data to a mathematical equation. A visual evaluation of figures 7 and 8 shows reasonable fit for most points below 7,000 vehicles per hour (vph).

Figures 7 and 8 reveal gradual, then noticeable, reductions in travel delay for the split intersection starting at a total entering flow 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 the computed delays shown in table 1, these simulated results yield approximately a 40-percent to 50-percent reduction 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 reduction in delay ranges from 50 percent to 60 percent for the same range of total entering flows.

A simple economic analysis provides very encouraging documentation of the substantial benefits of the split intersection. The computed results in figures 9 and 10 show the extent of savings per year in vehicle-hours and in equivalent costs for two selected peak flows. The following assumptions were used in the computations:

- Four hours of peak periods per day (h).
- Peak period occurs on more than 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).

The occupancy factor and the hourly cost of delay are given in an FHWA memorandum (April 1997) on "Departmental Guidance for the Valuation of Travel Time in Economic Analysis." It has been adjusted from 1995 to 1998 dollars using the consumer price index. This factor applies to all vehicles, including buses and vans.

Economic Benefits

A case study presents an economic analysis procedure for planning purposes. A single intersection is converted to a split intersection to serve the traffic demand for the next 10 years. After 10 years, a bridge will be required on the major highway over the crossroad to meet the growing traffic volumes. The split intersection is thus converted to a diamond interchange with the separated roadway serving as on and off ramps from the major highway. Although the assumed costs are reasonable, users should apply local estimates that meet their specific project needs. Some constraints are observed because of a broad variability and a limitation in the scope. The impact on adjacent properties is considered to be comparable to any other necessary improvement alternative. An isolated site does not require signal progression. Pedestrian and bicycle traffic is very rare.

Net benefits are expressed in present worth of the yearly savings minus the initial costs of right-of-way, construction, and signal. Estimated peak flow over the first five years is 5,000 vph, and a flow of 6,000 vph is assumed for the following five years. Equivalent cost-savings per year are provided in figure 10 and converted to the present with a rate of return of 0.06. Assumed costs are as follows:

- Land cost for 15-percent left-turning volumes (200-ft offset) ($16/ft2): $3,200,000
- Land cost for 30-percent left-turning volumes (300-ft offset): $4,800,000
- Construction cost for pavements and drainage: $ 583,000
- Signal cost: $ 80,000

The net present benefits are illustrated in figure 11. For the 15-percent left-turning volumes, a net benefit is derived after seven years. A net benefit for the 30-percent left-turning volumes kicks in after six years.

Additional savings are derived from postponing the bridge construction over the crossroad for several years. An estimated cost of embankment and pavement for extending and raising the mainline to the bridge is $1,021,000. The bridge cost is estimated at $928,000. Figure 12 displays the resulting present worth savings that could be derived by delaying the bridge construction for five to 10 years.

Conclusions and Recommendations

Split intersections are well-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 signal progression when the arterial signal synchronization is compatible with the optimal 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.

For high peak flows and higher left-turning traffic, the economic benefits are noticeable. These benefits can easily justify the conversion of a split intersection over its economic life. The split intersection provides noticeable economic benefits in postponing the construction of the bridge for a grade-separated diamond interchange until traffic growth requires it.

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.

A well-designed and coordinated signal timing should rely on accurate estimates and forecasts of flows on all approaches of the split intersection.

In the case of highly oversaturated conditions, the spill-back of left-turning traffic along the east-west highway blocking the intersections could be prevented by designing longer offsets between the two intersections and/or controlling left-turning traffic on the crossroad.
Although this study applies only to fixed signal timing, actuated timing could provide smooth and efficient operation for 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 7 and 8.

Ideally, a field study is recommended to validate the simulated findings. However, this is unlikely because (according to the literature) very few intersections in the world have been converted to two split intersections. Besides the two case conditions that are discussed in this article, other cases could likewise be simulated in CORSIM with differing traffic volume and roadway cross-section scenarios.

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