MEDIAN U-TURN DESIGN AS AN ALTERNATIVE TREATMENT FOR LEFT TURNS AT SIGNALIZED INTERSECTIONS

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ABSTRACT

Many signalized intersections experience recurring congestion and safety problems. For certain flow patterns and high traffic volumes, innovative or non-conventional designs are possible cost effective solutions. A median u-turn treatment at a signalized intersection is evaluated for a four-lane highway intersecting another four-lane road. The u-turn design is compared to a conventional geometry with direct left turning flows. TRANSIT-7F is used to optimize the signal timing and CORSIM to estimate traffic flow performance without validation or recalibration of the default parameters. A significant reduction in travel time is noted for the design with median u-turn at high volumes and high left-turning proportion. A reduction in stop time ranges from 10 to 40 seconds per vehicle.

INTRODUCTION

Conventional intersection designs often are not capable of alleviating congestion without incurring significant improvement costs and increased conflicts. A few states are considering and applying non-conventional treatments for high traffic volume intersections, especially those with high left-turning traffic volumes. Non-conventional intersections provide unique channelization of particular turning movements and indirect traffic movements (figure 1). Consequently, capacity is enhanced (with an increase in effective green) and delay may be reduced when the number of signal phases is reduced. Moreover, safety benefits are possible with separation and reductions of potential conflicts. Michigan has many boulevards that allow wide median u-turns to divert direct left-turns from the main signalized intersection. A paper by Levinson, et al. has reviewed the safety and operational performance of the Michigan experience over long corridors that were implemented in the 1960's (1). Reported accident reduction is about one third less than direct dual left-turn lanes. Capacity gains are about 18 percent higher for indirect median crossover versus dual-left-turn lanes. Florida and North Carolina use continuous green T-intersections where the right lane of the major road has a constant green signal. New York has built a continuous flow intersection with three legs where the left-turning traffic is channelized to the left side of the approach. The left-turning vehicles take advantage of the through green phase to turn left on the cross road without the need for an exclusive phase. Another similar intersection has recently been opened in Maryland. According to the NCHRP *Synthesis on Left-Turn Treatments at Intersections,* 26 agencies use indirect left-turn treatments, (2). Public education and proper advance signing are critical to achieving a successful redesign. This paper studies the traffic operational benefits of signalized median u-turns for left-turning vehicles making indirect maneuvers. A discussion of possible safety benefits is also provided.

CONFIGURATION

Figure 2 illustrates the intersection treatment analyzed in this study, which is similar to the illustration in figure 1 (third one from the top). Drivers who intend to turn left at the intersection have the advantage to naturally stay in the left lane. They cross the main intersection and take the left-turn lane downstream to make a u-turn. A lane is added on the right side of the other direction with a jug handle to cover the swept paths of large vehicles. The u-turning traffic is also provided with an acceleration lane on the right side of the crossroad. In this study, u-turn crossovers are provided on both sides of the major road only at 137 m (450') from the main intersection (stop-bar to stop-bar). The left-turning pockets downstream of the intersection are 122 m (400') long and are protected by u-turn signal. Minor road left-turning traffic is allowed to turn at the main intersection. This latter design is the selected case study and is based on the assumption that minor left-turning volumes are not high and that right-turning maneuvers for indirect left-turns could initially be counterintuitive. Lengths of the left-turn lanes and offsets could vary according to the peak left-turning traffic demand. A longer offset was used only for the highest flow scenario in this analysis with 500 vph of left-turning volume. Spillback is less likely because the cycle lengths can be shorter with fewer required phases and the u-turning traffic is mostly able to clear the left-turn lane in only one cycle, with longer phase splits. Moreover, the through movement always has a continuous green (in the direction of the u-turning movement) that can store excess left-turning vehicles and prevent a spillback. A wide median is necessary to accommodate large vehicles as in the Michigan u-turn design, unless a jughandle is provided (figure 2).

According to AASHTO's Policy on Geometric Design (3), a WB-15 design vehicle making a 180^o turn will require a minimum inside turning radius of 5.9 m (19') and a maximum outside turning radius of 14.1 m (46'). When converting a conventional intersection, additional land will only be required for the jughandle (or flaring/widening the median). The described geometric characteristics per approach are symmetrical along the four-lane major highway and the four-lane minor road.

A median u-turn design separates potential conflict points and reduces their locations in comparison to the conventional four-legged intersection (figure 3). From a safety perspective, dual left-turn lanes are likely to be more hazardous than median u-turn design. Dual left-turn lanes have wider exposed pavements that add extensive potential conflict area, and require more travel time for the cross street traffic. In particular, it will increase the yellow clearance time needed for the cross street phases. Hakkert and Mahalel derived a regression equation relating accidents to conflict points (4). The conflict points are converted into an index of traffic flows (x) that was calculated as the sum of the product of the flows at each conflict point for the entire intersection. The equation is of the simple linear regression form and explained 60% of the variation for a sample of intersections that are mostly without signals. This fitness measure is higher than most accident prediction models that relate accidents to highway factors. A reduction of conflicts combined with a reduction in the number of signal phases is likely to have positive safety implications. If the number of phases is reduced, drivers are faced with lesser critical decisions during yellow clearance time and all red (or dilemma zone).

MEDIAN U-TURN TRAFFIC PERFORMANCE

Although this study considers signalized u-turns only, unsignalized or permitted movements are reported to yield comparable travel time at low u-turning flows (5). No estimation of u-turning capacity is provided in the Highway Capacity Manual (HCM) (6). An estimated capacity of u-turns developed by Al Masaeid (for non-signalized openings) is slightly lower than the HCM capacity of left-turning traffic from the major road (7).

$$C = 799 - 0.32q$$

C = capacity (vph), and

q = conflicting flow rate (vph)

Although many left-turn treatments are described in NCHRP Reports 420 and 279 and the Synthesis 225, analysis is available only on some treatments comparing them to conventional designs (8,9,2). Hummer and Boone used a microsimulation model (NETSIM) to compare a standard four-legged intersection with a similar design that transfers the left-turning vehicles to a u-turn crossover (10). The u-turn crossover on the four-lane mainline is offset by 183 m (600') from the main intersection that is crossed by a two-lane road. Based on several combinations of through and left-turn volumes, the u-turn configuration required more travel time than a standard design. This result may be due to signal timing or the omission of acceleration lanes on the crossroad. The paper by Dorothy, Maleck, and Sarah (1997) also described a simulation of the operational effects of the Michigan median u-turn on a four-lane arterial road (5). Contrary to the previous paper, the authors concluded that indirect left-turning strategies with a signalized median crossover resulted in less travel time in most cases than conventional design (5). NETSIM was also used to simulate comparable geometries of an arterial section consisting of six intersections with a free flow speed of 72 km/h (45 mph). The range of median width from 12 to 30m (40 - 100') had no impact on the total travel time. U-turn crossovers were positioned at 200m (660') downstream of every main intersection.

According to the NCHRP Report 420, the Michigan u-turn treatment was cited as providing 20 to 50 percent capacity gains when left-turns are prohibited at intersections, with a two-phase signal. The referenced research in the NCHRP 420 was presented during the 1996 Annual Transportation Research Board (TRB) conference, but it was not published in a record. After more than two decades of experience with the Michigan u-turn treatment, several State studies have documented their safety benefits according to NCHRP 420 (8). A reduction of 30 percent injury accidents were reported, with substantial reductions in right angle, rear-end, left-turn, and head-on accidents.

ANALYSIS METHODOLOGY

Comparisons of typical intersections are applied for median u-turn treatments and conventional intersections with single and dual left-turn lane. A basic design of four-lanes intersecting four-lanes is considered where the major road is assumed to have a speed of 64 km/h (40 mph) and the minor road a speed of 56 km/h (35 mph). The typical median u-turn design is for signalized intersections with median u-turns for the left-turning maneuvers of the major road only (figure 2). The conventional design allows all direct left-turns within the main intersection. Microsimulation modeling is used to represent typical geometric designs with variations of traffic flows. CORridor SIMulation (CORSIM) is the simulation tool used in this study (11). CORSIM provides comprehensive capabilities, including traffic operational analysis, geometric design/traffic operational analysis, and assessment of mitigation strategies under congested conditions. The diagram for the median u-turn design is identical in length to the conventional direct left-turn design.

The length of left-turn lanes for the conventional design is 107m (350') on all approaches. Lengths of right-turn lanes on the crossroads are 76 m (250'). U-turns are offset by 137 m (450’), and corresponding left-turn lanes are mostly 122 m (400’) long. For the highest flow scenario only (7,000 vph), the median opening is provided at a longer offset of 167 m (550’) with the left-turn lane lengths equal to 137 m (450’). The mainline right-turn lane is extended up to the median crossover of the u-turn design. Acceleration lanes provided on the crossroad are 122 m (400') long. The comparison is conducted for a wide range of scenarios of balanced traffic flows where the opposing traffic volumes are equal. The ratios of minor to major road traffic volumes range from 20/80 to 40/60. Two separate cases consider 10 and 20 percent left-turning flows. Right turning flows are always assumed to be 10 percent on all approaches. Truck proportion is also assumed constant at 5% for all movements. Considering the complexity of signal timing, TRANSYT-7F was used to determine optimum signal settings with a range of cycle lengths from 60 to 120 seconds (12). Pre-timed signal settings are chosen for the conventional design with four phases. The typical u-turn signals have three phases at the main intersection and two phases at the u-turn opening. TRANSYT-7F simulates traffic flow in small time increments represented by a node/link scheme designed by the users. Sixteen cases of balanced flows are considered. Their total entering flows, from all approaches (including through right- and left-turns at the intersection)**,** range from 2,000 vehicles per hour (vph) to 7,000 vph. TRANSYT-7F was applied to each scenario for all cases to determine optimum signal settings for the conventional design and the median u-turn treatment (a total of 64 scenarios). For each scenario, the results were applied to typical CORSIM networks and simulated for a period of 1,200 seconds. All vehicle entry headways are set equal to the uniform headway defined as 3600 seconds/number of vehicles/hour/lane. At the start of the simulation the initialization period or “fill time” is set at 20 minutes to load vehicles on each sub network and get statistically meaningful results. Equilibrium was reached during this initialization period for all scenarios. For each scenario, up to five runs were tried with different random seed numbers to record average performance. However, the difference among these runs was minimal.

RESULTS

Although the diagram lengths for the conventional design and the median u-turn treatment are similar, travel time delay is not a comprehensive measure of intersections' effectiveness. The second type of design requires a longer travel distance for the left-turning vehicles on the major road. An average network travel time is a more consistent measure. A comparison of network travel time for 10 and 20 percent left-turn volumes between the two major types of intersections reveal considerable savings for the median u-turn treatment at high volumes. For 10% left-turning volumes with single left-turn lanes (figure 4)**,** noticeable differences start at total entering flows of 6,000 vph. Then, the savings rise rapidly from 10 to 40 seconds per vehicle (sec/veh). No analysis is conducted for dual left-turn lanes of the conventional design with 10 percent left-turning volume. For dual left-turn lanes with 20% left-turning volumes, figure 5 shows small savings in travel time from 5500 vph to 6,600 vph. Then larger savings are derived beyond 6,600 vph. For single left-turn lanes with the 20% left-turning volumes, noticeable savings in travel time start at 4,500 vph, and rise to about 60 sec/veh. Comparable trends are derived from the CORSIM analysis in terms of stop time (i.e., average time that a vehicle is actually stopped) for the two simulated cases at 10% and 20% left-turning flows. Figure 6 illustrates a comparison of percent stops (i.e., number of vehicle stops divided by number of trips) with single left-turn lanes for the conventional design only. The average proportion of vehicles that stop on the network is consistently lower for the u-turn configuration, by about 20 to 40% for the case with 10% left turns. For 20% left-turns, a noticeable reduction in percent stops starts at about 4,500 vph. Derived average travel times for the u-turning traffic compared to direct left-turning traffic is about 20 to 30 sec/veh higher because of the circuitous movement. Moreover, derived stopping time is also higher for the u-turning traffic by about 10 to 18 sec/veh. U-turning vehicles are likely to stop at the main intersection and in the left-turn bay downstream.

CONCLUSIONS AND RECOMMENDATIONS

- Although the average travel time for the u-turning traffic is higher than direct left turns, the overall reduction in the network travel time for the u-turn intersection treatment is significant for balanced flows. The major factor contributing to this saving in travel time for the u-turn treatment is high total volumes entering the intersection with high left-turning traffic. The volume threshold where the reduction in delay becomes noticeable will depend on the magnitude of left-turning volumes and total volumes through an intersection. Similarly, benefits are derived from a reduction in the percent of stops.
- A necessary and effective feature in geometric design is the provision of an acceleration lane on the cross road, although a minimum length was not investigated. Advantages of having longer left-turn lanes (greater than 350') for the conventional design are not noticeable according to the CORSIM analysis. Longer offset for the median u-turn design will slightly increase travel time for left-turning traffic, but the benefit to the network could be significant at high traffic volumes.
- The u-turn design is a less expensive remedy than dual left-turn lanes and is likely to be safer. Additional right-of-way is localized in the jug-handle instead of building extra parallel lanes at the approaches. Dual left-turn lanes require equal travel time as the u-turn treatment at low to medium volumes, and more travel time at higher traffic volumes.

Additional research is recommended as follows:

- To investigate the effects of unbalanced flows on opposite approaches.
- To investigate the application of actuated signals.
- To provide guidelines for the design and evaluation of median u-turn treatments such as threshold of traffic operational conditions and geometric features (minimum lengths of offsets).

- To investigate the safety impacts of reducing phases and reducing potential conflict locations.

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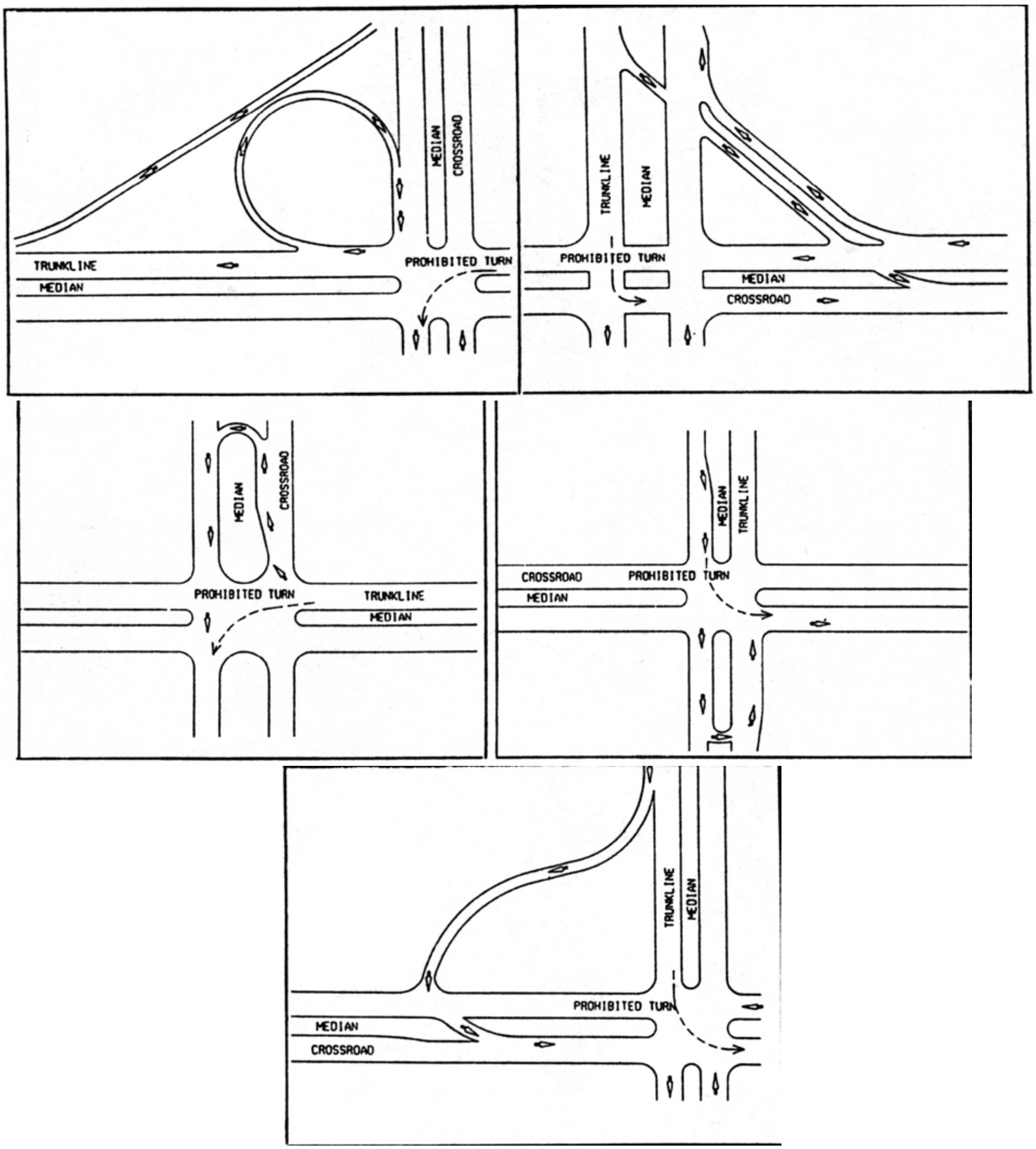

FIGURE 1 Alternative treatments for left-turn movements (2).

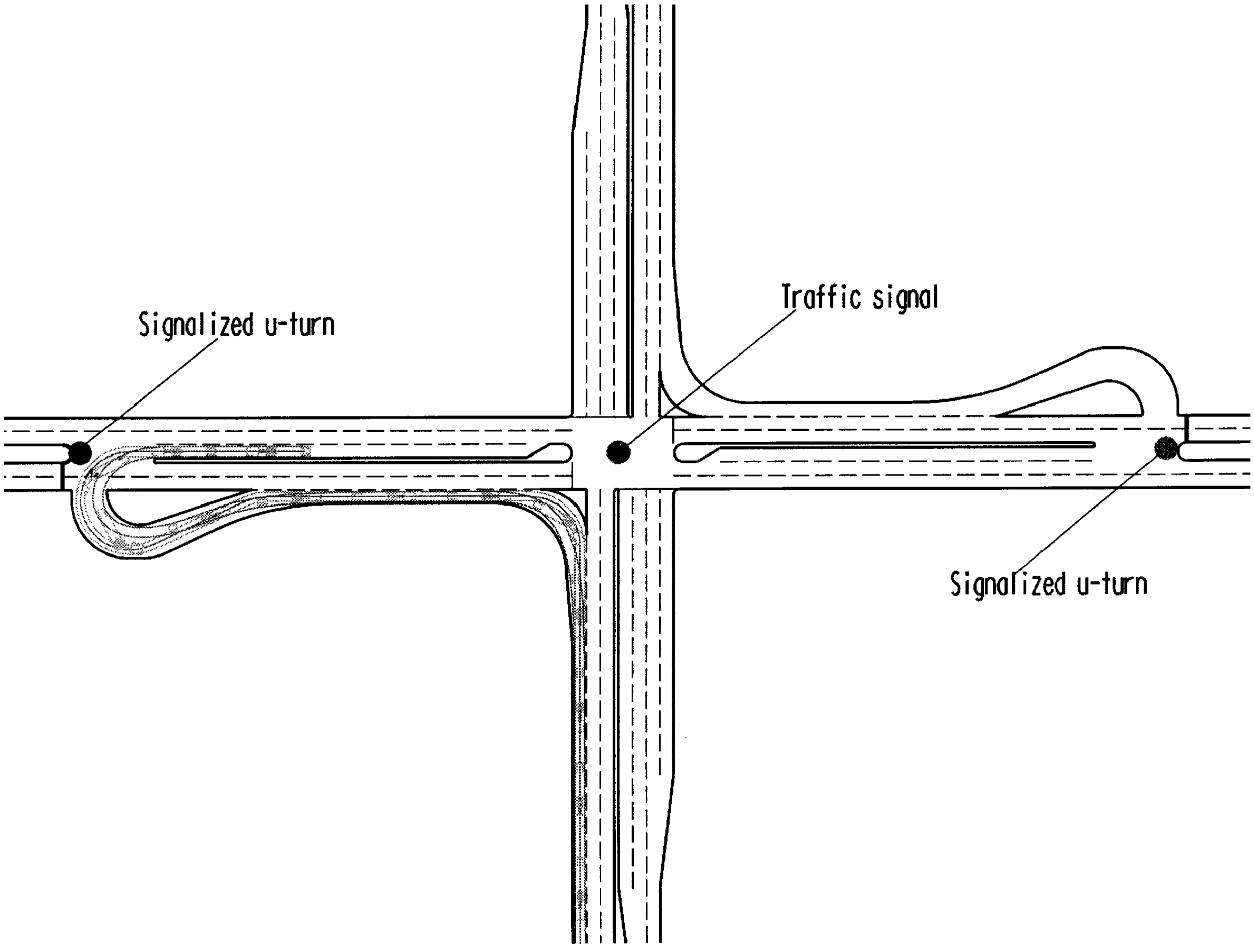

FIGURE 2 Typical median u-turn treatments used in this study (not to scale).

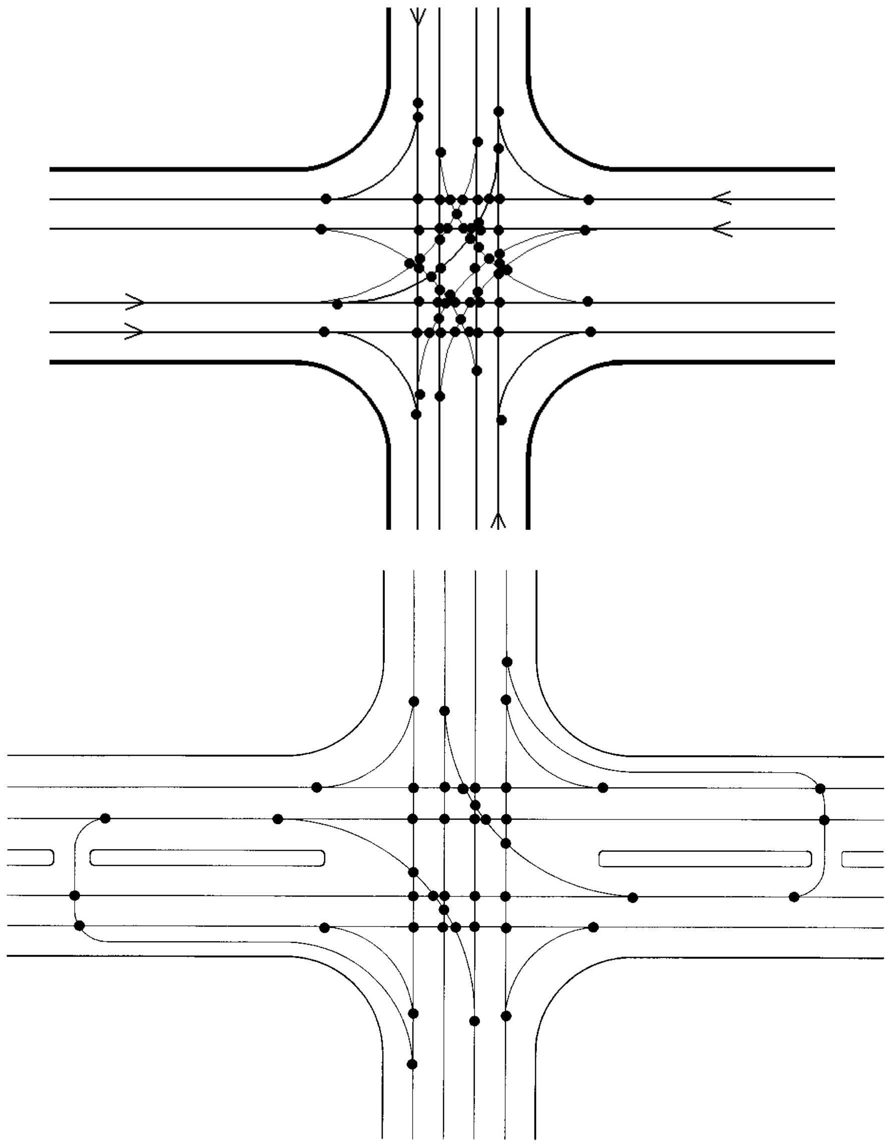

FIGURE 3 Potential conflict points for a conventional intersection with dual left-turn lanes (68 points), and a median u-turn treatment (44 points).

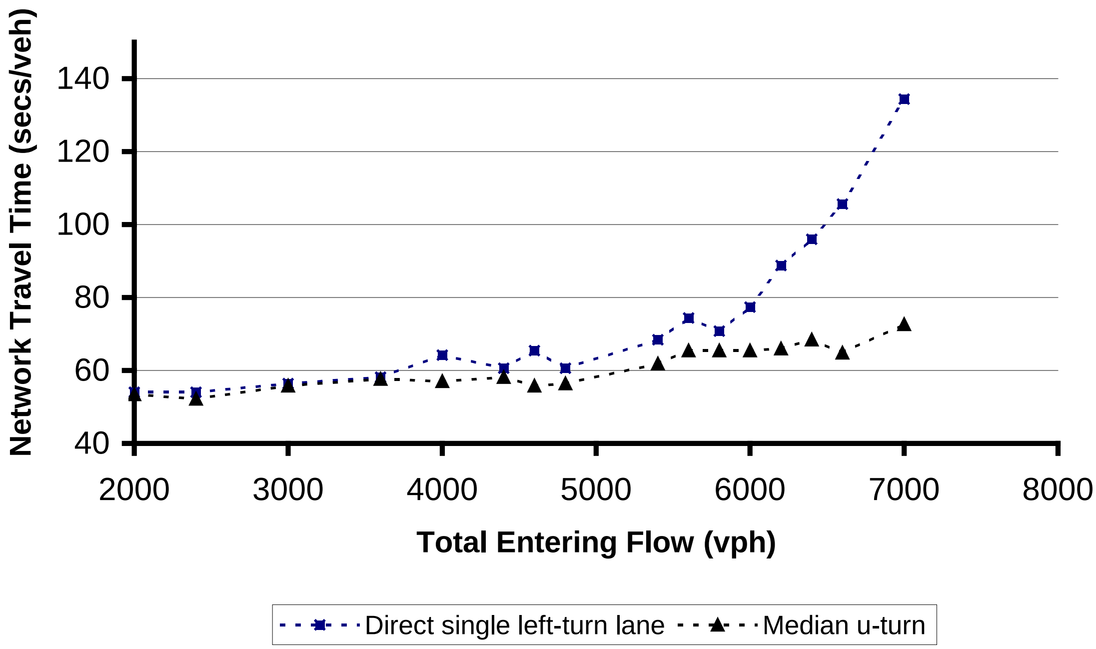

FIGURE 4 Network travel time derived from simulation at 10% left turn volume.

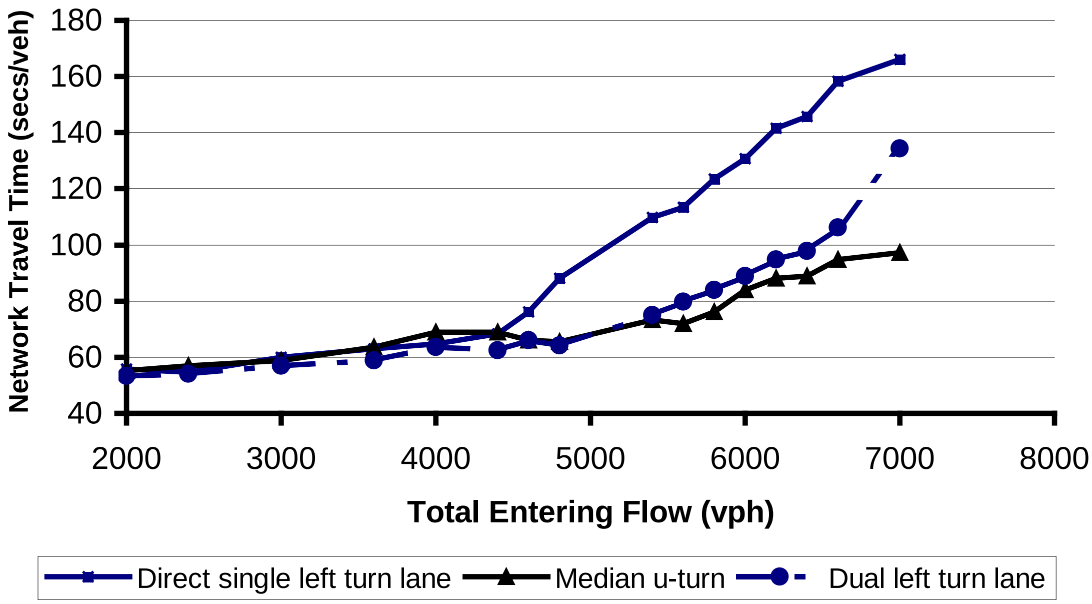

FIGURE 5 Network travel time derived from simulation at 20% left turn volume.

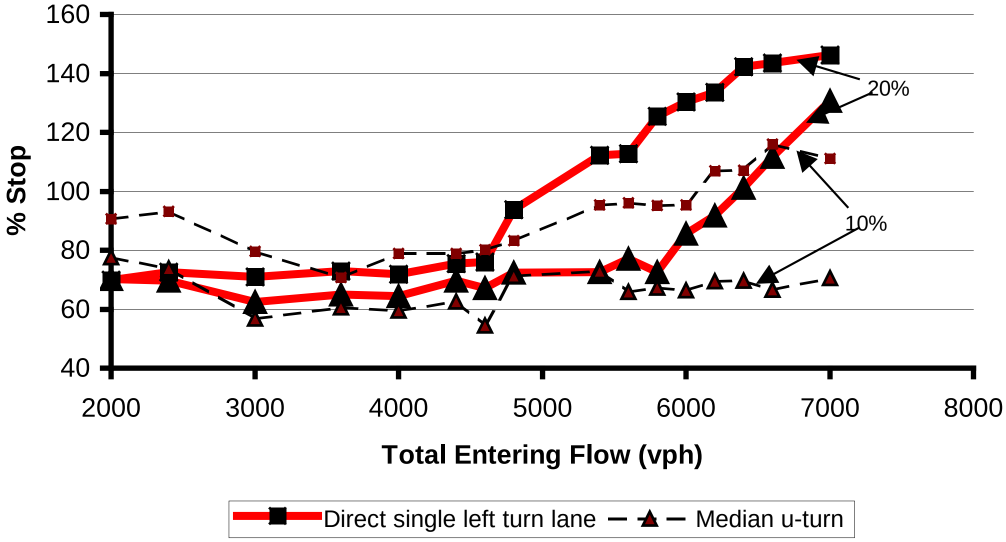

FIGURE 6 Percent stops derived from simulation.