Operational and Safety Impacts of Directional Median Opening on Urban Roadways: a Case Study in Houston, TX

Yi Qi, Ph.D.
Associate Professor and Chair
Department of Transportation Studies
Texas Southern University
Email: qiy@tsu.edu

Xiaoming Chen, Ph.D.
Research Assistant Professor
Department of Transportation Studies
Texas Southern University
E-mail: chenxs@tsu.edu

Guanqi Liu
Graduate Research Assistant
Department of Transportation Studies
Texas Southern University
Email: g.liu2751@student.tsu.edu

Yubian Wang
Research Associate
Department of Transportation Studies
Texas Southern University
E-mail: wangy@tsu.edu

Corresponding Author: Yi Qi

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ABSTRACT

As a design alternative for a median opening, directional median openings are normally used to restrict crossing and left-turn movements from minor streets to help avoid potential traffic conflicts. While this alternative may provide significant potential for safety benefits, its effectiveness is affected by a series of factors, such as geometry, traffic control, environmental conditions, and the type and placement of the downstream U-turn provisions. Inappropriate use of directional openings can result in extended travel time and worsened operations for minor streets, while providing very limited safety benefits for the whole corridor. The goal of this research was to investigate the operational and safety impacts of directional median openings on urban roadways. For this purpose, a case study was conducted on a 3,000-ft corridor on Jones Road in Houston, Texas, where four full median openings have been installed. The analysis of historical crash data and simulation-based analysis were conducted to investigate the performance of directional median openings compared with full median openings at the corridor. The results of this study showed that full openings should be avoided in the functional areas of signalized intersections and that the use of directional openings significantly reduced crossing-traffic conflicts at the opening locations, while slightly increasing lane-change conflicts in both the downstream and upstream areas. It also was found that use of directional openings may increase the congestion levels at the signalized intersections on the rerouting path.
INTRODUCTION

Over the past decades, many states and local transportation agencies have installed directional median openings on divided roadways to improve arterial safety and operational performance. A directional opening is normally used to restrict crossing and left-turn movements from minor streets to help avoid potential conflicts (Figure 1). At directional openings, vehicles exiting from the driveways have to make an alternative movement to finish the left-turn maneuver, which involves a right-turn followed by a U-Turn. A series of potential benefits may be achieved by installing directional-median openings, including reduced crash rates, increased traffic capacity, and better operational performance (1-6). However, the benefits of directional median openings depend largely on whether it is properly implemented and on several other factors, including geometric, traffic control, environmental conditions, and the type and placement of the downstream U-turn provisions.

In addition, there may be a number of issues associated with the use of directional openings:
1) additional travel distance/time, which may be a result of rerouting driveway-egress, left-turn traffic (using right-turn followed by a U-Turn), 2) increased traffic conflicts at the U-turn locations, 3) resistance from the business owners who are concerned about the accessibility of their businesses.

The objective of this study was to investigate the operational and safety impacts of installing directional openings on urban divided roadways. To that end, a case study was conducted at Jones Road - an urban, six-lane, arterial road in Houston, Texas. The approaches used in this study included a field survey, micro-simulation-based studies, and the analysis of historical crash data. The outcomes of this project will provide traffic engineers with findings and recommendations that help them understand the critical issues associated with the use of directional median openings so they can plan and implement this alternative appropriately on urban roadways.
REVIEW OF STATE-OF-ART STUDIES

To provide a full context for this study, existing studies associated with the operational and safety impacts of using directional median openings were reviewed thoroughly. This review focused on the following two aspects: 1) the impacts of directional median openings and 2) the impacts of indirect left-turns.

Impacts of Directional Median Openings

Several studies on the operational and safety impacts of directional median openings have been conducted. Gluck et al. (1999) indicated that converting full median openings to directional median openings can improve safety performance by reducing the crash rates by 20% (1). Potts et al. (2004) found that the crash rates on urban roadways for directional median openings were 48% and 15% lower than full median openings at three-leg and four-leg directional median openings, respectively (2). However, Castronovo et al. (1998) indicated that converting a full opening to a directional opening increased the rear-end crash rates, suggesting that a storage lane for left-turn vehicles should be considered (7). Levinson et al. (2005) concluded that the appropriate design of directional median openings at three-leg and four-leg intersections can reduce the crash rates by as much as 33% compared with full median openings (3). Taylor et al. (2001) found that rear-end and angle crashes were reduced significantly when directional median openings were installed, and adequate widths for the median and a left-turn bay should be provided (8). Hoffman et al. (1969) indicated that replacing a full median opening with a directional median opening reduced the total number of crashes by 62%, from 34 to 13, in a one-year period (4).

Impacts of Indirect Left-Turns

Previous research conducted by Liu et al. (2007) indicated that indirect left-turns from driveways generated 47% fewer conflicts than direct left-turns from driveways. Vehicles making a right turn followed by a U-turn generated 26% fewer conflicts than those making a direct left turn. Right turns followed by U-turns at signalized intersection will result in delays and more travel time than direct left-turns at driveways (5). Levinson et al. (2005) found that indirect left turns can improve safety performance when two or more directional median openings are applied to serve one full median opening (3). Potts et al. (2004) concluded that crashes associated with U-turns and left-turn movements occurred infrequently. There is no strong evidence to show that the number of U-turns and left turns at a median opening has a strong connection with crash rates and frequencies (2). Zhou et al. (2007) demonstrated that indirect left turns provided better safety with regard to traffic conflicts and fewer effects on through-traffic operations of a major highway (6). Lu et al. (2005) indicated that indirect left turns improved operational performance to a greater extent than direct left turns at median openings. Vehicles making right turns followed by U-turns at median openings in advance of signalized intersections experienced less delay and travel time than those making U-turns at signalized intersections (9).
Overall, the results from the previous studies indicated that directional median openings can improve arterial safety and operational performance if they are well designed and planned.

**METHODOLOGY**

In this study, to investigate the critical issues related to the use of directional median openings, the following approaches were used:

1) **Historical crash data analysis:** to identify the openings at which safety issues exist and directional openings can be applied as a potential solution for reducing crash risk. For this purpose, crash frequencies were calculated for different types of crashes and different openings along the selected roadway segment based on five-year historical crash data.

2) **Simulation-based analysis:** to compare the operational and safety performance of openings with and without the implementation of directional median openings. For this purpose, the microscopic simulation software, VISSIM, was used to model a baseline scenario that represented the existing geometry with full openings, along with two hypothesized scenarios with directional median openings at the selected site.

**FIELD SURVEY**

For the field survey, the study locations were selected based on several criteria. First of all, the selected location had to be a median-divided roadway. Second of all, the roadway segment selected had to have driveways along two sides of street for generating left-turn and right-turn traffic demands. Finally, feasible locations for indirect left-turning vehicles to perform U-turns had to be available.

**Jones Road - between FM 1960 and Fallbrook**

To collect data for this study, a field survey was conducted at a roadway segment on Jones Road in Houston, Texas, during both the morning and afternoon peak-traffic periods for three weekdays. Jones Road is a six-lane road that connects U.S. Highway 290 and State Highway 249, and this road was designed and is operated by Harris County, Texas.
FIGURE 2: Jones Road between FM 1960 and Fallbrook

<table>
<thead>
<tr>
<th>Observed Left-turn Volume (AM peak vph/ PM peak vph)</th>
<th>Opening 1</th>
<th>Opening 2</th>
<th>Opening 3</th>
<th>Opening 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southbound</td>
<td>12/11</td>
<td>5/11</td>
<td>15/16</td>
<td>14/34</td>
</tr>
<tr>
<td>Northbound</td>
<td>13/13</td>
<td>37/35</td>
<td>30/61</td>
<td>21/59</td>
</tr>
</tbody>
</table>
The basic roadway and traffic conditions at this roadway segment are provided below:

- Six-lane, arterial road connecting Texas State Highway 290 and Texas State Highway 249
- Posted speed limit is 45 mph
- Its length is about 3,000 ft with signalized intersections (FM 1960 and Fallbrook) on each end
- Four full median openings exist along this road segment
- Peak-hour traffic is approximately 1,200 to 1,600 vph in the peak direction.
- A mixture of residential and business areas exists along this road. Jones Square Shopping Center and Cypress Fairbanks Medical Center are beside the road segment.
- There are 32 driveways, and the left-turn traffic volumes from these driveways are between 10 to 80 vph. Among them, driveways facing Opening 4 have the heaviest left-turn volumes.
- The median openings are closely spaced, ranging from 285 to 820 ft.
- Approximately 5% commercial traffic
- During study period the observed operating speeds were generally 5-10 mph above posted speed

Traffic Data Collected

The following data were collected by different methods at the study site:

1. Traffic volumes were collected during the observational periods and averaged for both the morning and afternoon peak hours. Videos of the traffic were recorded in the field. They were used to count the traffic volumes for movements for all of the openings and signalized intersections along the study segment.

2. Corridor travel time was collected based on a floating-car survey. The travel times were collected along the entire segment of Jones Rd. The start and end points for measuring the travel time were indicated in Figure 2. Along the segment, the average northbound and southbound travel times were collected for both the morning and afternoon peak hours.

3. Left-turn travel time was collected at openings 1 and 4, as shown in Figure 2. The left-turn travel time was collected from the time a vehicle arrived at the back of a queue, if any, to the time the vehicle completed the left-turn maneuver, either entering the target driveway from the mainline or merging onto the mainline travel lanes from a driveway.

CRASH DATA ANALYSIS

To investigate the safety performance at the roadway segment, five-year crash data (from January 2006 to December 2010) were analyzed. At first, based on the location of the crashes, a total of 100 crashes were identified at the four openings along this segment. Then, the police reports for these 100 crashes were reviewed carefully.

As shown in Figure 3, Opening 1 had the highest crash frequency, i.e., 63 crashes during the five-year period. Among these crashes, 44 only caused property damage, and 19 involved
injuries. Figure 3 also shows the crash frequency by types at Opening 1.

![Figure 3: Comparison of Safety Performance](image)

(a) Crash frequency by different severity levels at all 4 openings

(b) Crash frequency by different crash types at Opening 1

**FIGURE 3: Comparison of Safety Performance**

According to crash information available in the police reports, the crashes at Opening 1 are likely attributed to two causes:

1) *Median opening is located within the functional area of a signalized intersection*

Opening 1 is located only 595 feet away from the major signalized intersection of Jones Rd and FM 1960. At this intersection, there is high right-turn traffic volume and without exclusive right-turn lane. During peak hours, eastbound right-turn vehicles spill back to the driveway facing Opening 1, and this requires egress vehicles from this driveway to cross the waiting queue to reach Opening 1. Since the drivers’ sight distance was impaired by the vehicles in the queue, the drivers of egress vehicles failed to detect that northbound through vehicles were approaching...
from the leftmost, through-traffic lanes (Figure 4), which may result in T-bone crashes. According to the police reports, 11 crashes that occurred at this opening during the most recent 5-year period were caused by this problem.

![Figure 4. Crashes Caused by the Queue Spillback at Opening 1](image)

2) Narrow median width

The insufficient width of the median, approximately 15 ft, is another major issue that caused crashes in this opening. According to the crash report, 31 of the 63 crashes at this opening were associated with the narrow median. The insufficient median width at this location was unable to accommodate the entire vehicle, which caused the conflicts between the vehicles stored at the openings and the through vehicles.

According to the findings above, one potential solution to mitigate the safety problem at Opening 1 is to convert it to a directional median opening, as shown in Figure 5. In this way, the egress left-turn vehicles will not stop in this opening that has a narrow median. In addition, using directional median opening also will prevent the egress left-turns from driveways from crossing this opening, which may be blocked by the waiting queue from the downstream signalized intersection. To further investigate the impacts of converting Opening 1 from a full opening to a directional opening, a simulation-based study was conducted.

![Figure 5. Converting Opening 1 to a Directional Opening](image)
SIMULATION-BASED STUDIES

Simulation-based studies were conducted to evaluate the operational and safety impacts of using the directional opening design at Opening 1. For this purpose, three simulation scenarios associated with the conversion of a full opening to a directional median opening at this study site were developed, as shown in Figure 6.

Scenario I was the base case, which represented the existing geometry. Scenarios II and III represented the situations in which the study opening was changed from a full median opening to a directional median opening, with direct left turns from driveways not allowed.

In Scenario II, U-turns were allowed at FM 1960, so the westbound left-turn vehicles from the driveways were rerouted to make U-turns at the signalized intersection of Jones Rd. and FM 1960. In Scenario III, U-turns were assumed to be prohibited at FM 1960, and vehicles exiting from driveways and intending to make left-turns were rerouted to the nearest median opening downstream of the intersection of Jones Rd and FM 1960. A ‘NO U-TURN’ sign should be installed when this operation is implemented.

Figure 6 shows the rerouted left-turn alternatives from the driveways of the opening and the characteristics of the three experimental scenarios. The signal timings were optimized in Synchro for these three simulation scenarios, which eliminated the effects of signal timing and focused on the effects of the opening’s settings.
Scenario I Base Case (full opening)

Scenario II U-Turn allowed at FM 1960 (directional opening)

Scenario III U-Turn allowed at downstream opening of FM 1960 (directional opening)

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Opening Type</th>
<th>Location where left-turns make maneuver</th>
<th>Signal setting</th>
<th>Driveways where egress traffic has to make indirect LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Full</td>
<td>Left-turn at Opening 1</td>
<td>Optimized</td>
<td>None</td>
</tr>
<tr>
<td>II</td>
<td>Directional</td>
<td>U-turn at Intersection of Jones Rd at FM 1960</td>
<td>Optimized</td>
<td>Driveways 1, 2, 3, and 4</td>
</tr>
<tr>
<td>----</td>
<td>-------------</td>
<td>------------------------------------------</td>
<td>-----------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>III</td>
<td>Directional</td>
<td>U-turn at downstream opening</td>
<td>Optimized</td>
<td>Driveways 1, 2, 3, and 4</td>
</tr>
</tbody>
</table>

**FIGURE 6: Experimental Scenarios**
Calibration of the Base-Case Model

VISSIM was used to model and analyze the three experimental scenarios. The base-case simulation model was developed to replicate the observations at the study corridor, including the traffic, geometric, and environmental conditions. The model calibration included adjusting the model parameters so that the simulated results agreed with the observed travel times (both through and left-turn travel times). The results of the calibration are summarized in Table 1. Overall, the calibrated models had a significant correlation with the observed datasets. The simulated travel times along the corridor had a average error of approximately 10%. The model also yielded reasonable estimates of travel times for the left-turn movements from the mainline.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Travel Time Across Entire Segment</th>
<th>Travel Time at Median Opening 1</th>
<th>Travel Time at Median Opening 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observing</td>
<td>Simulated</td>
<td>Absolute Error</td>
</tr>
<tr>
<td>NB</td>
<td>181.0</td>
<td>165.7</td>
<td>-15.3</td>
</tr>
<tr>
<td>SB</td>
<td>134.0</td>
<td>148.8</td>
<td>14.8</td>
</tr>
<tr>
<td>SB Left Turn</td>
<td>40.4</td>
<td>40.9</td>
<td>-0.5</td>
</tr>
<tr>
<td>NB Left Turn</td>
<td>15.9</td>
<td>12.5</td>
<td>-3.4</td>
</tr>
<tr>
<td>SB Left Turn</td>
<td>22.0</td>
<td>23.9</td>
<td>1.9</td>
</tr>
<tr>
<td>NB Left Turn</td>
<td>11.7</td>
<td>12.9</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Operational Impacts of Directional Median Opening

Outputs from the VISSIM models, such as travel time, delay, and level of service (LOS) were collected for investigating the operational impacts of the directional median opening.

Impacts on the Focused Movements

Table 2 provides the simulation results of travel time for three focused movements of this study: 1) through movements along the studied segment, 2) the left-turn movements from the mainline at the study opening, and 3) the left-turn movements from driveways at the study opening. The results showed that the rerouted left-turn traffic at Opening 1 will increase the travel time of the through movement slightly along the study segment. For the left-turns from the mainline, travel times in Scenarios II and III were similar to that in Scenario I. This was to be expected, because vehicles still can make direct left turns from the mainline even after the directional opening is used. However, the travel time for the egress left turns from the driveways was increased dramatically in Scenarios II and III, because these vehicles cannot make direct left turns after the use of the directional opening. Overall, the results in Table 2 indicate that only the rerouted left-turn traffic from the driveways will be affected by the using of a directional opening at this location, and the impacts on other movements are minimal.
TABLE 2: Simulated Travel Times (in seconds)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Through movements along the corridor</th>
<th>Left-turns from the mainline</th>
<th>Left-turns from the driveways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northbound</td>
<td>Southbound</td>
<td>Opening 1 Northbound</td>
</tr>
<tr>
<td>I: Base Case (full opening)</td>
<td>116.3</td>
<td>136.7</td>
<td>9.4</td>
</tr>
<tr>
<td>II: U-Turn allowed at FM 1960 (directional opening)</td>
<td>117.1</td>
<td>138.5</td>
<td>9.0</td>
</tr>
<tr>
<td>III: U-Turn at downstream FM 1960 (directional opening)</td>
<td>116.5</td>
<td>140.0</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Impacts on the Signalized Intersection

The impacts on the neighboring signalized intersection also were analyzed. Table 3 presents the delay and LOS of the intersection for the three experimental scenarios.

TABLE 3: Signalized Intersection Delay and LOS from Simulation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Delay (second)</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: Base Case</td>
<td>41.5</td>
<td>D</td>
</tr>
<tr>
<td>II: U-Turn allowed at FM 1960 &amp; Jones</td>
<td>42.5</td>
<td>D</td>
</tr>
<tr>
<td>III: U-Turn at downstream FM 1960 &amp; Jones</td>
<td>55.4</td>
<td>E</td>
</tr>
</tbody>
</table>

The results indicated that rerouted left-turns from driveways at Opening 1 (by using the directional opening) increased the delay at the signalized intersection, especially for Scenario III. This occurred because the v/c ratio for the northbound through movement was already quite high (i.e., = 1.08) at the signalized intersection (Jones Rd. and FM 1960). In Scenario III, all the re-routed, left-turn vehicles must go through this signalized intersection. By adding the re-routed, left-turn traffic to this critical movement (northbound through traffic), more congestion resulted at this intersection, and the overall delay at the intersection increased significantly.

Impacts on Network-Wide Performance

The network-wide impacts of using the directional median opening were also compared for the experimental scenarios. Table 4 summarizes the results of the network-wide average delay and speed.

The results showed that, at network levels, Scenarios I and II yielded similar results, while Scenario III had the worst operational performance over the network.
TABLE 4: Average Arterial Delay and Speed from Simulation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Delay (s/veh)</th>
<th>Average Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: Base Case (full opening)</td>
<td>55.2</td>
<td>27.1</td>
</tr>
<tr>
<td>II: U-Turn allowed at FM 1960 (directional opening)</td>
<td>56.0</td>
<td>27.6</td>
</tr>
<tr>
<td>III: U-Turn at downstream FM 1960 (directional opening)</td>
<td>70.5</td>
<td>24.6</td>
</tr>
</tbody>
</table>

Safety Impacts of Directional Median Opening

To analyze the safety impacts of the directional median opening, we used the Surrogate Safety Assessment Model (SSAM) developed by Siemens for a FHWA project (10). SSAM was designed to conduct vehicle-to-vehicle conflict analysis by directly processing vehicle trajectory data exported by micro-simulation software, such as VISSIM. This method is useful for conducting safety assessment for new roadway designs that have not been built or assessing operational strategies that have not been applied in the field. In this study, the simulated traffic conflicts, including crossing, lane-change, and rear-end conflicts were derived from the SSAM for the safety analysis.

Traffic Conflicts in Each Impacted Area

After conversion to a directional opening, egress left-turn movements were eliminated from the driveways and left turns had to make right turns followed by U-turns (RTUT), as the blue and green paths in Figure 7 show. In this study, the areas for which safety performance may be affected by converting the full median opening into a directional opening were referred to as "impacted areas." As shown in Figure 7, four impacted areas were bounded by red boxes. They are Area 1 (the northbound approach to intersection FM 1960 and Jones Rd.), Area 2 (Opening 1), Area 3 (the southbound approach to Opening 2), and Area 4 (Opening 2). In order to conduct the traffic conflict analysis, all conflict data were collected from the impacted areas (1 to 4) individually and analyzed type-by-type.

FIGURE 7: Impacted areas in which safety performance can be affected by the directional opening
Figure 8 shows the number of simulated traffic conflicts (lane-change and crossing) at each impacted area. Converting the full opening into a directional opening led to a significant decrease of crossing-traffic conflicts at the studied opening (Impacted Area 2); however, the change also resulted in an increase in the lane-change conflict rates in almost all areas. The reason was that, for the egress left-turn vehicles that attempted to make indirect left-turns, they had to quickly change to the leftmost lane right after they had turned right from the driveway. It led to more lane-change-related conflicts.

**Figure 8: Number of simulated traffic conflicts (crossing and lane-change) at each impacted area**

**CONCLUSIONS**

In this study, the analysis of historical crash data and simulation-based analyses were conducted to investigate the operational and safety impacts of using directional median openings at the studied corridor. The results of this study led to some key findings and recommendations. At first, the
The results of crash data analysis reinforced the following knowledge:

- Full openings should be avoided in the functional areas of intersections, especially when traffic conditions (e.g., queue spill back from the intersection and heavy left-turn egress from driveways) pose operational or safety problems.

- Sufficient width of the median is important for the safety of openings. Where the right-of-way is available, a median width of 25 ft (11), which can provide sufficient refuge for at least one left-turn vehicle, is strongly recommended.

According to the results of the simulation-based study, it was found that use of directional opening will have the following impacts:

- **Safety impacts**: after converting a full median opening to directional opening, crossing conflicts at the opening location will be reduced significantly, while lane-change conflicts will be increased slightly at both downstream and upstream areas.

- **Operational impacts**: use of the directional opening may increase the delay for the egress traffic from driveways that will need to make indirect left-turns. In addition, using directional opening may increase the congestion levels at the signalized intersections that are on the rerouting paths.

- **Selection of re-routing paths**: the selection of rerouting paths largely depends on the available capacity along the path to accommodate the re-routed traffic. Paths with bottlenecks (high V/C ratios) should not be used as re-routing paths.

The findings above will help traffic engineers in their efforts to design and implement better directional median openings on urban roadways. Note that, these findings are drawn from a study of a single corridor based on traffic simulations. In the future, field studies at different corridors with various geometric and traffic conditions need to be conducted to further verify these findings. In addition, ongoing and future studies are needed on determining the conditions (e.g. traffic volume thresholds) under which a directional median opening may be appropriate.

**ACKNOWLEDGEMENTS**

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REFERENCE


