
ASSESSING THE FEASIBILITY OF CONVERTING TWO WAY LEFT TURN LANE INTO BUS RAPID TRANSIT LANE

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ABSTRACT

Bus Rapid Transit (BRT) is an important element of bus transit systems that involves preferential treatments to en route buses. Although past research and experience have demonstrated the benefits of BRT to the transportation system, implementation of BRT on congested local arterials having minimal to no right of ways remains a challenging issue. A feasible solution is to use the Two Way Left Turn Lane (TWLTL) in the center of local streets for BRT purpose during the peak hours. However, a TWLTL can be utilized in two different ways for this purpose, either directly as a median BRT lane or as a reversible general traffic lane (so that the curb lane is spared for BRT). Without a clear understanding of the impacts of traffic characteristics, intersection layouts, and traffic signal control on each of the two alternatives, a decision is usually difficult to make as to which option serves best to transit vehicles while at the same time brings minimum impacts to the general traffic. This paper evaluates the performance of a median BRT lane and curb BRT lane considering varying traffic conditions and physical configurations of the street and the intersections. The pros and cons of each alternative are also specified according to simulation analysis.

Keywords: Bus Rapid Transit, BRT, TWLTL, Curb BRT Lane, Reversible Operation, BRT station, BRT Signalization

INTRODUCTION

Bus Rapid Transit (BRT) is an advanced mode of mass transit which is rapidly gaining popularity as a mode of public transport because of its inherent characteristics. A BRT system is relatively easier to build on arterial roads where there are enough leeway for right of way expansion (1, 2). On congested roads or streets with limited right of way, however, implementing BRT systems has been a challenging endeavor. A typical congested local street usually has a greater degree of accessibility, limited space for expansion and a Two Way Left Turn Lane (TWLTL) in the center of the street for easy access to adjacent properties. These basic constraints limit the leeway on the part of the designer for fitting a BRT system onto an existing street. The flexibility in the operation of BRT can be extended to local streets which are congested and lack the required space for constructing an additional BRT lane. Roadway widening is considered expensive due to property requirements and disruptive to surrounding development. To work around this, an existing lane from the congested network should be modified such that a BRT system is possible without adding additional lanes. A feasible solution is to use the TWLTL in the center of local streets for BRT purpose during the peak hours. However, a TWLTL can be utilized in two different ways for this purpose, either directly as a median BRT lane or as a reversible general traffic lane (so that the curb lane is spared for BRT). For a reversible BRT lane, a single lane can be operational in two directions. By being operational in two directions, the median BRT lane can accommodate vehicles traveling one way in the morning and another in the afternoon. For the reversible BRT curb lane, the extreme left and right lanes would each operate as a BRT lane (one at a time) and would also change with time of day.

The purpose of this study is to assess the impacts of creating a BRT lane on a local roadway by essentially changing the lane behavior, not only of the transit system and the general traffic, but also at the stations. A segment in Austin, Texas has been used as a case study to analyze the impact of the various possible alternatives of a single lane reversible BRT. This segment is on North Lamar Boulevard from West Braker Lane in the north to West Rundberg lane in the south. It is also essential to see how the network performs using both the central BRT lane and the curb BRT lane. Furthermore, the different station locations (near-side, far-side, and mid-block) may also impact the performance of the network which is evaluated as well in this study.
Two alternatives have been considered for comparison in VISSIM simulation:

- Alternative 1 - reversible BRT lane operating on the TWLTL
- Alternative 2 - reversible BRT lane operating on the curb lane

Both alternatives require the modification of the central TWLTL either directly into a BRT lane or into a through lane, by making the curb lane available for the BRT. Schematic layouts of the two alternatives are shown in Fig.1 and Fig.2. The values presented in this paper are just reference values for a unique set of conditions. The actual values and results in any given network will depend on local geometry, vehicle distribution, and vehicle volume.

![REVERSIBLE BRT LANE](image)

**Figure 1** Alternative 1 – TWLTL Converted to a BRT Lane

![BRT LANE AM PEAK](image) ![BRT LANE PM PEAK](image)

**Figure 2** Alternative 2 - Curb Lane Converted to a BRT Lane

**BRT CONSIDERATIONS**

The following two sections aim to address both pros and cons of the BRT alternatives. It is important to understand how a network or intersection can be both positively and negatively impacted by the location of the station as well as different intersection geometries. No two intersections are alike and for this reason it is very important to determine what aspects of the two alternatives best appeals to the network being studied. Variables such as disruption of present land use development, cycle length, intersection geometry, vehicle distribution, vehicle volume, storage capacity, right of way width, number of transit passengers and bus headway will all play an important role in determining the best BRT method for a given network (2,3). The subsequent sections do not recommend the best BRT method but instead identify aspects of each BRT alternative that will impact network performance.

**Median BRT Lane Considerations**
There are a number of pros and cons of the median BRT lane compared to the curb BRT lane arrangement. Fig. 3 shows an intersection accommodating a median BRT lane. One of the main issues regarding the median BRT lane is that it complicates the intersection layout and signalization methods since the left-turn movement parallel to the through bus lane would have to turn from the right-hand side of the median BRT lane. In order to accommodate such an unusual intersection layout, the left turning vehicles must be given a protected left turn signal and never a permitted left turn phase (4). The protected left turn would eliminate the conflict point of left-turning vehicles and the through bus lane because they would never have the same phase and their phases would never overlap. The left-turning vehicles in the north and south direction would have a protected phase and the BRT lane would be the same phase as the through north/south movement.

A median BRT operates better than a curb BRT when access to commercial driveways is considered because the addition of a curb BRT will ultimately block traffic traveling into/out of adjacent commercial businesses when the curb lane is not shared with right-turning vehicles. By relocating bus operations to the median BRT lane, the access movements to and from the adjacent properties will not impact bus operations like it would on a curb BRT lane. The problem for the median BRT lane arises for the left turning movements from the main street onto the minor streets which is jeopardized due to the elimination of the auxiliary lane. The elimination of the two way left turn lane will introduce a greater volume of vehicles at the intersection because vehicles that would normally use the TWLTL to turn into adjacent commercial/residential development will not be allowed to do so because the TWLTL would have been eliminated and converted into a BRT only lane. To accommodate vehicles that normally would have used the TWLTL to make a left-turn into adjacent property, a “U-turn allowed under signal control” sign should be present at the intersection. Fig.4 is an example of a U-turn sign that should be located at an intersection when a BRT median lane is present. This sign was taken from an example of a BRT project in Canada (5) and has not yet been inserted into the United States Manual on Uniform Traffic Control Devices (6). Depending on the size of the intersection, when implementing the U-turn on protected arrow sign, there should also be a “no right-turn on red” sign located at the side street. This will eliminate the conflict point for U-turn and right-turn vehicles. U-turn continuity lines can also be implemented in order to emphasize the correct vehicle path and positive directions for the U-turn vehicles. By placing the U-turn lane to the right of the median BRT lane, it ensures the vehicles have a large enough radius to adequately make a U-turn. Furthermore, in order to reduce the need for longer left-turn bays and the need for a longer cycle length, the U-turn sign can be placed at an intersection with less side street traffic.

When considering driver expectations, all BRT alternatives will cause problems. One way to aid the driver and ensure a positive vehicle path is to use continuity lines to provide positive guidance for all vehicles. When operating a median or curb BRT lane it is helpful to use simultaneous left-turn phases to reduce delays and avoid split phase operations. This is a case when continuity lines will be most helpful due to the left turning vehicles traveling close to each other. Using continuity lines will reduce the risk of a head on or side swipe collision. Delineation and pavement marking are usually used in practice for the same purpose. At some times it might be helpful to use a barrier-separated BRT lane. For high speed roads, it is recommended to use concrete barriers for separation when vehicle to bus head on collision rate is unacceptable. However, studies have found that the addition of barriers might have a significant impact on emergency vehicle access to adjacent property (7).
The curb BRT lane will operate better than the median BRT lane in some cases and in other cases the median BRT lane will outperform the curb lane. Fig. 5 shows an intersection layout for a typical curb BRT lane. Please note the TWLTL is converted to a general mixed traffic lane due to the addition of the curb BRT lane and the curb BRT lane is shared with right-turning vehicles. The most obvious problem that arises from the addition of a curb BRT lane is the issues that are caused by the buses and right-turning vehicles sharing the outer most lane. Since the buses are in the same lane as right-turning mixed traffic, buses will have to wait on cars to make their right-turn before they can pass through the intersection. Furthermore, buses that stop at the near-side station will cause delay for right-turning vehicles.

Unlike the curb lane, the median BRT lane separates general traffic from the busses to the greatest possible extent. When the curb lane is used strictly for transit vehicles, it would also be used for general mixed traffic to make right-turns into private access development or side streets. Laws should be put in place for vehicles to enter the curb lane a certain distance in advance before their right-turn. Implementing a curb BRT lane impedes the movements for the right and left turns from/to the T-intersections. The mixed traffic is required to yield to the BRT before taking these turns. Fig. 6 shows the...
possible conflict point for vehicles traveling from the T-intersection when the curb lane is used for busses only.

Figure 5  Intersection with Curb BRT

Figure 6  Conflict Point for Vehicle Traveling from T-Intersection

PEDESTRIAN CONSIDERATIONS

Now that there is an understanding of the pros and cons of each BRT alternative, it is important to consider the safety of the bus passengers and the ease at which they can enter/exit the bus. The first station location to be analyzed will be the mid-block station for both alternatives. The most dangerous station location for the median BRT lane is the mid-block. Pedestrians who wish to enter the bus must cross 2 lanes of traffic in order to enter the bus located in the median lane. Providing mid-block stations for a median BRT system usually needs special treatments (8), detailed discussion of these treatments is beyond the scope of the study. For this study, although the mid-block station is studied as an option
associated with both median and curb BRT lanes, it is not recommended when implementing a median BRT lane. Furthermore, the curb BRT lane with station located mid-block will not have the same consequences as the median BRT. Since the bus will already be on the curb and the bus entrance will be directly adjacent to the curb, pedestrian safety will not be an issue. Another problem with the mid-block station is its distance from the main streets. Mid-block stations are usually located between two main streets. Since a majority of the passengers will be walking from commercial and residential property on the two minor streets, the station located mid-block would essentially make the transit system less convenient for passengers. The median BRT with station located mid-block may also cause problems for waiting passengers. Since, in this case study, the TWLTL is converted to a BRT lane, there is no space for a passenger waiting facility in the middle of the street while using the available roadway envelope only. This may not be the case in networks with a traditional median BRT lane where there is space for a passenger waiting area in the middle of the street.

The next station location for consideration is far-side. The far sided station with a median BRT lane also poses a threat to passengers. The main problem of accommodating a median BRT with a far-side station relates to the passengers using the crosswalk to cross the street to the station far-side. When passengers try to enter the bus stopped far-side they will require a pedestrian phase. Since the passengers are walking across the street far-side, they will be blocking multiple traffic paths. However, if the passengers were to walk across the street to a near-side bus stop, they would only be blocking traffic in one direction.

The last station location considered for this study is a near-sided station. The main issue that arises from the near sided station is the additional delay buses experience from waiting for passengers. For example, buses that enter the intersection might enter at the beginning of their phase but they still have to stop for passengers. When the passengers are finally on the bus, the green phase has just ended and in turn causes the bus to wait the entire cycle until it has a green light again. With stations located far-side, the bus travels through the intersection and is free to go whenever the passengers are on the bus.

**BUS HEADWAY**

The bus headway, more commonly known as the time interval between buses, will impact the overall network performance when utilizing a curb BRT lane. However, when using the median BRT alternative, the bus headway will not impact the average travel time or delay (fixed-time only) because the median BRT layout allows for a dedicated, bus-only lane. When using a curb BRT lane, the vehicle delay will increase as the bus headway decreases. This is a result of more busses blocking right-turning vehicles. Furthermore, the smaller the bus headway the more the mixed traffic will be delayed due to buses stopped near-side. Bus headway is an important issue and will negatively impact the passengers if the headway is too high and the mixed traffic if the headway is too low. It is recommended the bus headway be discussed to determine the optimum headway for both transit passengers and vehicles.

**CONVERSION OF EXISTING ROADWAY TO BRT FRIENDLY LAYOUT**

The selection of a particular BRT running way type to suit an existing local street depends upon the geometry of the local street. In situations of limited or no availability for widening of the roadway envelope, a BRT lane can be carved out from an existing lane by suitably modifying the lane behavior. Most local streets have dense commercial and/or residential development surrounding them requiring greater levels of accessibility and usually have a TWLTL in the center to aid this. A typical TWLTL is shown in Fig.7. As per the TxDOT Roadway Design Manual (9) the design width of the TWLTL varies from 12 ft to 16 ft depending upon the design speed, with higher widths for higher design speeds. TCRP Report 117 (10) requires that the minimum lane width for a high speed BRT operation be 11 ft with 1 ft
spare for delineators. The TWLTL thus satisfies the minimum requirement for the BRT Lane and can be converted into a single BRT lane.

![Figure 7](image)

**Figure 7** A Typical TWLTL with T-Intersections

**VISSIM SIMULATION PARAMETERS**

To analyze the impact of the conversion of a TWLTL into a BRT lane a simulation of the traffic conditions on the study segment of North Lamar Boulevard was created and studied using VISSIM4.3, necessary treatments to traffic signals are made in simulation as well ([11]). A small section on North Lamar Boulevard in Austin (TX) which has limited space for expansion was chosen to be modeled into VISSIM. It stretches from West Braker Lane to West Rundberg Lane and is approximately 1.45 miles in length. Having limited right-of-way makes it necessary to design the geometric layout for BRT within the available roadway envelope only. One way to fit the BRT into such a roadway is by converting the existing lane into a single reversible BRT lane. The TWLTL in the center of the section is identified for this conversion. Although the TWLTL is an essential lane for a street with multiple left turning demands, it is also a lane which could be converted into a BRT specific lane. The impact to the capacity of the through lanes is expected to be minimum because the number of through lanes remains unchanged.

Fig.8 shows the location of the study section highlighted and Fig.9 shows the existing intersection layout. For the simulations, the existing layout was converted to a curb BRT lane layout and a median BRT lane layout. The existing intersection of West Rundberg and South Lamar consists of a total of six lanes in each direction. Lamar Street has two left-turn lanes in each direction as well as a through and a through-right in each direction. West Rundberg consists of a left turn lane, two through lanes, and a right turn only lane in both directions. The locality around the section is congested with limited right-of-way and the section has multiple T-intersections (Fig.8). Some data used for software modeling the entire network was optimized. This included the signal timing plan which was optimized in Synchro6.0 and inputted into VISSIM. The bus headway was inputted as 12 minutes. The vehicle inputs used for the simulation runs for each of the alternatives were kept constant which assured a common base for comparison. Information such as the volume entering the network and volume distribution at the intersection of Lamar and Rundberg was obtained from the City of Austin Traffic Department. Table 1 shows the vehicle volume and distribution used for the network. The T-intersections volumes were assumed and ranged from 100-200 vehicles per hour depending on the size of the feeder street. The simulation results
displaced are for a period of 1 hour including warm up time. Three stations were located on the simulation network – two on the major intersections and one in-between the section of nearly 1.45 miles. The performances are evaluated for the station positions far-side, near side and on the mid-block. A separate transit line was created dedicated to the BRT service. The bus used the same phase as the traffic and priority was given to the bus at every conflict point. The regular vehicles were made to yield to the BRT first, before taking their respective turns, at both the signalized and the non-signalized intersections. The parameters selected for the analysis evaluate the performance of the study section quantitatively. The results have been obtained through the simulation runs and compared in the subsequent discussion.

Figure 8 Study section from Austin, TX
Table 1 Vehicle Volume and Distribution obtained from the City of Austin

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Lamar (Northbound)</th>
<th>Lamar (Southbound)</th>
<th>Rundberg (Westbound)</th>
<th>Rundberg (Eastbound)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Through</td>
<td>Right</td>
<td>Total</td>
</tr>
<tr>
<td>7:00-7:15</td>
<td>13</td>
<td>86</td>
<td>19</td>
<td>116</td>
</tr>
<tr>
<td>7:15-7:30</td>
<td>25</td>
<td>101</td>
<td>43</td>
<td>169</td>
</tr>
<tr>
<td>7:30-7:45</td>
<td>31</td>
<td>139</td>
<td>33</td>
<td>203</td>
</tr>
<tr>
<td>7:45-8:00</td>
<td>34</td>
<td>134</td>
<td>38</td>
<td>206</td>
</tr>
<tr>
<td>Total</td>
<td>103</td>
<td>460</td>
<td>133</td>
<td>694</td>
</tr>
</tbody>
</table>

VISSIM RESULTS

The following four tables highlight the performance of the network for the two BRT lane options and can aid in the decision to determine the most effective BRT method considering both alternatives. Table 2 and Table 3 show the median BRT lane network performance for all vehicles and buses, respectively. Table 4 and Table 5 show the curb BRT lane network performance for all vehicles and buses, respectively. It is to be noted that the station location affects the network performance of the system. It can be observed from Table 2 and Table 4 that for both the median BRT and curb BRT lane the far-side
station performs the best and results in the lowest average delay. As mentioned previously, this is because the near-side station requires the buses to stop at the station possibly at the beginning of their green phase. When the passengers are finally on the bus, the green phase has just ended and the bus is forced to wait the entire cycle length before it can proceed through the intersection. This ultimately increases the average delay. For stations located far-side, the bus can travel through the intersection whenever it approaches the stop line and the passengers loading the bus and the signal are not related. This is why the far-side station location is the most attractive. Furthermore, the near-side station will complicate bus signal priority because of the bus stopping at the station before passing through the intersection.

The results also show that, when utilizing the curb BRT lane, the near-side station creates problems for the buses and vehicles. When right turning vehicles and through buses are both using the curb lane (proposed in this research), the curb lane near-side station causes the buses to wait for right turning vehicles to make their respective turn. Furthermore, the vehicles in the right turn lane experience an increased queue due to the buses stopped near-side. This is why, as shown in Table 4 and 5, the curb near-side station is the highest delay for both the vehicles and buses.

**Table 2** Comparing the network performance parameters for a median BRT lane (all vehicles)

<table>
<thead>
<tr>
<th>Parameter from VISSIM (All Vehicle Types)</th>
<th>Far-Side</th>
<th>Near-Side</th>
<th>Mid-Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay time per vehicle [seconds], All vehicle types</td>
<td>23.0</td>
<td>25.5</td>
<td>24.3</td>
</tr>
<tr>
<td>Average speed [mph], All vehicle types</td>
<td>21.8</td>
<td>20.3</td>
<td>21.3</td>
</tr>
</tbody>
</table>

**Table 3** Comparing the network performance parameters for a median BRT lane (buses)

<table>
<thead>
<tr>
<th>Parameter from VISSIM (Buses Only)</th>
<th>Far-Side</th>
<th>Near-Side</th>
<th>Mid-Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay time per vehicle [seconds], Buses</td>
<td>118.1</td>
<td>116.4</td>
<td>124.7</td>
</tr>
<tr>
<td>Average speed [mph], Buses</td>
<td>21.6</td>
<td>21.9</td>
<td>21.1</td>
</tr>
</tbody>
</table>

**Table 4** Comparing the network performance parameters for a curb BRT lane (all vehicles)

<table>
<thead>
<tr>
<th>Parameter from VISSIM (All Vehicle Types)</th>
<th>Far-Side</th>
<th>Near-Side</th>
<th>Mid-Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay time per vehicle [seconds], All vehicle types</td>
<td>21.26</td>
<td>24.85</td>
<td>22.4</td>
</tr>
<tr>
<td>Average speed [mph], All vehicle types</td>
<td>22.4</td>
<td>21.1</td>
<td>22.3</td>
</tr>
</tbody>
</table>
Table 5 Comparing the network performance parameters for a curb BRT lane (buses)

<table>
<thead>
<tr>
<th>Parameter from VISSIM (Buses Only)</th>
<th>Far-Side</th>
<th>Near-Side</th>
<th>Mid-Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay time per vehicle [seconds], Buses</td>
<td>96.7</td>
<td>145.8</td>
<td>102.8</td>
</tr>
<tr>
<td>Average speed [mph], Buses</td>
<td>21.9</td>
<td>17.8</td>
<td>21.4</td>
</tr>
</tbody>
</table>

CONSIDERING VARYING TRAFFIC CONDITIONS

The network segment in Austin, Texas which was used for the case study has a relatively common vehicle distribution. There is a greater number of through vehicles on both Lamar Street and Rundberg. On Lamar Street, there are a greater number of left turn vehicles than right turn vehicles and on Runberg it is the opposite. The question that arises from the issue of varying traffic conditions is how the different BRT alternatives and station locations are impacted by different vehicle volumes and distributions. This section addresses issues with each alternative when a non-traditional vehicle distribution is present (i.e. heavy right turn volume). The scenarios that will be addressed are heavy right turn volume, heavy U-turn volume, and heavy left-turn movement. These scenarios were run in the simulation software and compared. For the simulations, all approaches were set to 450 vphpl for through movement and 200 vphpl for both left and right turn lanes. Once this was complete, the signal timing plan was optimized in Synchro6.0 and imported into VISSIM. The average delay was then recorded for both alternatives and the volumes were slowly increased. Simulations were run and results were recorded for a right-turn volume of 200, 250, 300, 350, 400, 500, 600, 800, 1000, and 1200 vphpl and the intersections left-turn volume was increased from 200 vphpl to 250, 300, 350, and 400 vphpl. The left and right turn volumes were never changed at the same time to avoid conflicting results.

Figs.10, 11, 12(a), and 12(b) show the results for the varying traffic scenarios. It can be seen in Figure 11 how an increased left-turn volume affects each BRT alternative. In Fig.10, the average delay is not significantly increased when the left-turn volume is increased. This is because, when utilizing a curb lane for BRT purpose, there is a permitted plus protected phase for left-turning vehicles. Unlike the curb BRT lane, the median BRT lane requires a protected phase only for left-turning mixed traffic due to the bus lane located to the left of the left-turning vehicles. As a result of this, the median BRT lane intersection experiences increased delay when the left-turn volume in increased. This can be seen in Fig.11.
Figure 10  Curb BRT Lane Intersection Delay, All Vehicles, Increase Left-Turn Volume

Figure 11  Median BRT Lane Intersection Delay, All Vehicles, Increase Left-Turn Volume
Fig. 12(a) and 12(b) show how an intersection will perform using a curb BRT lane when there is an increased right-turn volume. Fig. 12(a) shows the average delay for all vehicles and Fig. 12(b) shows the average delay for buses. It can be observed from the two figures that the near-side station causes greater delays than far-side and mid-block stations. Furthermore, the results show that, once the intersection crosses the 600 vphpl right-turning volume threshold, the near-side station creates significant problems. This is a result of right-turning mixed traffic experiencing delays when a bus is stopped near-side. When the bus is stopped at the station, right turning vehicles cannot make right-turns due to bus blockage. In addition to this, buses wishing to stop near-side are delayed by vehicles waiting to turn right. For this reason, near-sided curb lane stations are not recommended for vehicles volumes above 600 vphpl.

Figure 12(a)  Curb BRT Lane Intersection Delay, All Vehicles, Increase Right-Turn Volume
One consideration for the intersection is heavy U-turn volume. Heavy U-turn volume at an intersection is generated from the elimination of the TWLTL. Vehicles that would normally use the TWLTL to turn into adjacent property are forced to go to the intersections to turn around due to the elimination of the auxiliary lane. Obviously, the type of development adjacent to the TWLTL will determine the vehicle volume generated from the network. For example, an entrance to a residential subdivision with 1,000 houses will generate more traffic than an entrance to a shopping center with two small stores. The type of development around the network should be considered before making a BRT decision. It is recommended a real data set be used and simulated in traffic software to determine the impact surrounding development will have on the elimination of the TWLTL. The type of surrounding development will play an important role in the number of U-turn vehicles at the intersection. The severity of the impact will depend on the type of business and/or development. “If the development is residential or if the trip was non-discretionary (doctor/lawyer/car dealership), it can be postulated that the individual would be familiar with the access and adjust his/her route to allow a right-turn maneuver. The implications are considered more severe where the access is being restricted to a discretionary type of trip (coffee shop, variety store, fast food operation). In these cases it is likely the customer would proceed to another location rather than consider out-of-the-way travel to access the location (12).” For networks with non-flexible development, it can be assumed that there will be a heavy U-turn volume (13). This would also impact the crossing street that would require a “no right-turn on red”. When development adjacent to the TWLTL is non-flexible, a curb BRT lane might be more suitable for the network.

A median BRT lane should not be used when there is a heavy left-turn volume at the intersection. The addition of the median BRT lane, compared to the curb BRT lane, will create additional traffic who wish to make a U-turn at the intersection. This will add to the vehicle volume in the left-turn bay. A curb BRT lane will in no way add to the left-turn volume and should be considered when there is already heavy left-turn movement. Furthermore, the transit vehicles traveling in the median BRT lane require the left-turn vehicles have a protected phase only due to the through BRT lane being located to the left of the left

Figure 12(b) Curb BRT Lane Intersection Delay, Buses, Increase Right-Turn Volume
turning mixed traffic. When there is a heavy left turn volume, a curb BRT lane will perform better because the left-turning vehicles will be allowed a short permitted phase as well as a protected phase.

**BRT ALTERNATIVES GUIDANCE CHART CONSIDERING TRAFFIC VOLUMES**

Fig. 13 summarizes the results of this research and can help transportation engineers determine the best BRT alternative for a specific, unique network. The legend at the bottom of the chart explains what the letters within mean. The right and left-turn volume is highlighted on the horizontal and vertical axes, respectively. Once the intersection right-turn volume is chosen a vertical line can be drawn down from the horizontal right-turn axis. After this is complete and the left-turn volume is determined, a horizontal line can be drawn from the vertical left-turn axis. Where the right-turn and left-turn lines cross, this is the recommended BRT alternative assuming a station location has already been chosen. For example, an intersection with a right-turn volume of 700 vphpl and a left-turn volume of 250 vphpl, a median BRT lane is recommended for intersections with stations located near-side and a curb BRT lane is recommended for intersections with stations located either far-side or mid-block. This guidance chart was derived from the intersections simulated in VISSIM comparing average vehicle delay when different traffic volumes were considered.

![Figure 13 BRT Alternatives Guidance Chart Considering Traffic Volumes](image)

*Figure 13* BRT Alternatives Guidance Chart Considering Traffic Volumes (Note: N-M stands for Nearside station – Middle Lane; M-M stands for Mid-block station – Middle Lane; F-C stands for Far-side station – Curb lane etc.)
SUMMARY & CONCLUSIONS

This paper addresses the issue of the convertibility of a local street into a BRT lane by focusing on the Two Way Left Turn Lane. A feasible solution is to use the Two Way Left Turn Lane in the center of local streets for BRT purpose during the peak hours. However, a TWLTL can be utilized in two different ways for this purpose, either directly as a median BRT lane or as a reversible general traffic lane (so that the curb lane is spared for BRT). The limitations used for the analysis were minimal availability of right-of-way on the sides of the street. It can be determined from the simulation values that the two BRT alternatives and 3 station locations will have a somewhat similar effect to a normal network. However, intersections with non even vehicle distribution and networks with special characteristics will require attention in order to determine the most effective bus rapid transit alternative. This paper addresses these special characteristics that will impact what BRT method is chosen and addresses issues to be discussed by professionals while planning for a BRT line. Furthermore, items such as pedestrian safety should be discussed because traffic simulation software will not take this into account. Each BRT alternative will be suitable for specific network characteristics. The figure developed from this research (Fig.13) can aid engineers in the decision of what BRT method will result in the least delays for the network which they are studying. Engineers who can predict left and right turn volumes for a signalized intersection can use this chart to determine the appropriate BRT alternative assuming a station location has already been chosen. A simulation using existing settings or a prototype simulating the alternatives and station locations on a larger scale is considered valuable to verify the BRT impact on the performance of a network being studied.
REFERENCES