Modeling the Traffic Impacts of Transit Facilities using Dynamic Traffic Assignment

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Word Count:
Text: 4,203 (Abstract: 170)
Tables: 2 x 250 = 500
Figures: 11 x 250 = 2,750
Total: 7,453

Submission Date: August 1, 2012
ABSTRACT

This paper demonstrates the capabilities and benefits of using dynamic traffic assignment (DTA) to analyze traffic impacts caused by transit services. The City of Austin’s proposed urban rail system is used as a case study. The urban rail connects the CBD, the University of Texas at Austin campus, and other large traffic generators. The majority of the rail system shares right-of-way with traffic. However, several segments have completely dedicated guideway. Previous analyses have focused either on microsimulation (which is limited in spatial area and does not consider route choice changes) or regional planning (which typically lacks detailed inputs and does not directly model transit impedances in the traffic assignment process). DTA provides a connection between these two methods: it can model route choice behavior using realistic inputs at a fine time scale across a large spatial area. Five scenarios with varying mode split percentages were modeled. At low ridership levels, corridors with major geometric modifications experienced more congestion. This caused travel pattern changes, increasing the volume on nearby parallel corridors.
INTRODUCTION AND MOTIVATION

Implementation of new or expansion of existing transit systems can have significant and wide-ranging impacts on traveler behavior. With the growth of bus rapid transit in the United States (1) and the serious investment in light rail over the past two decades (2), it is imperative for planners to quantify and fully understand these impacts – especially the effects on vehicular traffic. The transit system can affect automobile users in several ways: signal priority or at-grade rail crossings can cause extra driver delay, users may switch from automobile use to the transit mode helping to mitigate congestion, drivers may switch their route (perhaps avoiding corridors with several bus lines), or the transit system can fundamentally change user travel patterns. Transportation planning agencies as well as research entities have used several methods to estimate these traffic impacts. One can broadly group these procedures into two categories: corridor-specific analysis and regional planning.

One of the first documented corridor-specific studies to estimate vehicular impacts was conducted in the early 1980s by Cline et al (3). The study used microsimulation software to quantify the delay experienced by drivers at intersections with LRT crossings. Since then, microsimulation has become standard practice in transportation planning. Several studies have continued to investigate delay at at-grade rail intersections and where rail corridors share right-of-way (ROW) with automobile traffic (4–6). A plethora of research has also been aimed at using microsimulation software to determine the transit signal priority scheme that minimizes automobile delay (7–10). Furthermore, microscopic analysis has been applied to situations where existing right-of-way is converted from vehicular use to transit use (11). The majority of corridor-specific studies only investigated automobile delay due to transit impedances. Delay is only a small portion of all traffic impacts; in microscopic level analysis, route choice is non-existent or greatly simplified. Due to the nature of users interacting with each other across the entire network, traffic impacts can be felt far from the actual point of impedance. For instance, delay may cause automobile users to change their route choice producing effects in areas outside the analyzed corridor.

There is limited research on regional level traffic impact analysis. Most transportation planning agencies indirectly capture changes in vehicular use through the mode choice step in the traditional four-step model (12). Essentially, planners estimate the number of users who will switch from the automobile mode to the new transit mode. This may be done through surveys, utility functions, or through elasticity values from the literature (13, 14). Once this is done one can estimate the reduction in vehicle miles traveled – which can be used to quantify changes in vehicle operating, emission, and crash costs. Traffic assignment is then conducted capturing changes in route choice behavior. The inclusion of route choice modeling is important as shown in a recent case study in Melbourne, Australia (15). Changes to the transit system caused dramatic effects not just in the CBD but also, and more significantly, in the suburban areas. However, most regional level traffic impact analyses are not detailed enough to directly model transit impedances during the traffic assignment process. Sometimes, though rarely, corridors with transit activity may be modeled with reduced capacity.

The purpose of this paper is to demonstrate the usefulness, benefits, and capabilities of dynamic traffic assignment (DTA) when applied to traffic impact analysis. The proposed urban rail in Austin, TX is used as a case study. Most available DTA software is mesoscopic in nature and provides regional scope analysis at a fine time scale. Therefore, DTA is fully capable of modeling detailed signal timings and transit schedules. Also, DTA produces space-time vehicular trajectories, which completely describe the state of the transportation system. From these trajectories route choice behavior, queue formation, and dynamic travel times can be observed at the regional level. DTA provides what both standard corridor-specific and regional planning analyses have been lacking: it can model route choice behavior with realistic, detailed inputs at the large-scale level.

The next section briefly describes the geometric and operational characteristics of the proposed urban rail. The subsequent section details how the rail was modeled and inputted into the dynamic traffic assignment program. Then a detailed analysis is conducted focused mainly on changes in route choice behavior.
THE PROPOSED URBAN RAIL SYSTEM

The proposed urban rail connects the three major employers of Austin: the University of Texas at Austin (UT-Austin), the State of Texas, and the downtown central business district. A central hub is located in the downtown area, providing access to the Austin-Bergstrom International Airport as well as the Red Line commuter rail. Access is also provided to the north-eastern Mueller development area as shown in Figure 1 (16). From the airport to the CBD hub as well as from UT-Austin to the Mueller development, the rail service acts as a light rail system with limited stops. Through campus and the downtown area, the urban rail acts as a streetcar.

The urban rail transit system would provide two-way service for each corridor shown in Figure 1, except at the following one-way streets: Guadalupe, Lavaca, 9th, 10th, 17th, and 18th Streets. However, limited geometric changes occur to the existing transportation system; the rail shares ROW with traffic in the outside lane in each direction. The streetcar will be powered by an overhead electrical system. Each car has a capacity of 140 passengers, is 66 ft long, 11.4 ft high, and 8 ft wide (17). Four major changes occur to the existing network:

1. Guadalupe/Lavaca Corridor – one lane is converted into a shared urban rail and bus rapid transit lane; no automobiles are allowed. This occurs at 4th Street through 17th Street.
2. San Antonio Street – one lane is converted into a dedicated rail guideway.
3. 4th Street – one lane is added in the westbound direction.
4. San Jacinto Boulevard – one lane is added in the southbound direction between M.L.K Boulevard and Dean Keeton Street. It has dedicated ROW for the rail service.

IMPLEMENTING THE PROPOSED URBAN RAIL IN THE DTA SOFTWARE

Most available DTA software programs are simulation-based and fully capable of producing the traffic impact analysis conducted in this paper (e.g., Dynameq, DynaMIT, DYNASMART, and DynusT). The inputs necessary for the DTA process include: the transportation network with known link capacities and free-flow speeds, traffic signal timings, transit schedules, and an origin-destination matrix for each assignment period. This dynamic O-D table may be estimated from an activity-based model or converted from a traditional four-step model through diurnal profiling and random number generation. For each assignment/departure period (which ranges from several seconds to several minutes depending on the level of detail needed), traffic is loaded onto the network and user equilibrium is approximated. Therefore, the traffic assignment for each period is dependent on the previous traffic distributions. User equilibrium is achieved when every used path between the same origin and destination has equal and minimal travel time (i.e., no user can switch paths and reduce their travel time). Thus, the diversion and other flow changes due to transit are modeled behaviorally and reflect drivers seeking to minimize travel cost.

User equilibrium is attained through an iterative process. Once an initial traffic distribution has been assigned to the network, path travel times (including the shortest path) are calculated for each origin-destination pair. Then a percentage of traffic not located on the shortest path is switched onto the shortest path. This can be done through a variety of methods. The Method of Successive Averages (MSA) is the approach used in this paper. MSA shifts users onto the shortest path each iteration in predetermined percentages. The typical ratio used is \(1/p\), where \(p\) is the iteration number. As is common with all traffic equilibrium problems, convergence to the equilibrium is only attainable in the limit. Therefore, a convergence criterion is used to stop the process once traffic flows are reasonably close to equilibrium. The output of DTA is time dependent traffic flows, which can be used to determine dynamic traffic times, v/c ratios, densities, and speeds (18, 19).
FIGURE 1  City of Austin proposed urban rail system [Source: Urban Rail Partners].
The simulation-based DTA software, Visual Interactive System for Transportation Algorithms (VISTA), is used in the traffic impact analysis. VISTA is based on the cell transmission model (CTM). CTM divides the network into sections (cells). The length of the cells are equal to the distance traveled by a typical vehicle in the assignment period. The cell’s capacity, free-flow speed, and vehicle occupancy are known for each time period. Therefore, the model can track the inflow and outflow of each cell (i.e., the network traffic flows). Several refinements of the original CTM have been made to VISTA, including the incorporation of traffic signals, advanced intersection movements, and fixed route transit. More information regarding VISTA and its web-based interface is found in (20). A thorough explanation of CTM is described in (21) and (22).

Description of Base Network

The base network consists of 1,253 links, 456 nodes, 86 centroids, and 2,542 origin-destination pairs. The model covers the downtown area, the State Capitol, and the UT-Austin campus as shown in Figure 2.

FIGURE 2 Base case network and urban rail routes.
Creation of Routes

The preliminary engineering reports only identified the proposed corridors; no specific route scheme was discussed. Therefore, the authors divided the corridors into routes based on engineering judgment. As shown in Figure 2, four routes were created: Downtown to the Mueller development, Austin Airport to West Campus, the Guadalupe and Lavaca Loop, and the Downtown Hub to the Red Line connector. The design headway on all routes is 10 minutes. Where routes overlap, headways are 5 minutes (such as where the Austin Airport to West Campus route overlaps with the Downtown to Mueller route at San Jacinto).

Scenarios

Five scenarios were modeled each with a differing percentage of drivers switching from the automobile mode to the new urban rail:

1. Base Case Scenario – no rail implementation.
2. Worst Case Scenario – rail implementation, but no automobile users switch their mode.
3. 4% Scenario – 4% of vehicle users switch their mode, only where service is available.
4. 8% Scenario – 8% of drivers switch to the rail service, where available.
5. 16% Scenario – 16% of drivers switch to the rail service, where available.

Availability was determined by the location of each zone’s centroid in relation to the proposed urban rail stops (see Figure 1). For the downtown and campus areas, urban rail transit is available to the user if his/her origin and destination centroids are within a 1/3 mile radius of a rail stop. 1/4 of a mile is the typical design walking distance for bus transit (23). Since the urban rail provides greater comfort and potential travel time savings compared to bus, we assumed users are willing to walk a greater distance. In areas where the urban rail acts as a light rail transit service a 1/2 mile buffer was used, as recommended in (23).

The base network is a sub-network of a larger regional model of Austin. Since the external nodes of the sub-network represent many centroids in the regional network, estimating the mode split was more complicated for areas outside the downtown and university regions. For each external link, an O-D path analysis was conducted in the regional model – meaning that every path using a particular external link was determined. From this information, one can calculate the fraction of travelers using that link who have access to the urban rail. This percentage is multiplied by the mode split (4%, 8%, and 16%) to determine the overall mode split of that external connector. ArcGIS was used to determine which centroids were in the buffer area of the rail stops as shown in Figure 3.
RESULTS

One hundred iterations were performed for each scenario. The simulation period is from 7:00 AM to 9:00 AM. Convergence was measured through the cost gap percentage, which can be interpreted as the percent increase of travel time an average user feels over the shortest path travel time. The cost gap and the user’s average travel time at convergence for each scenario are shown in Table 1. Also shown in Table 1 are the cost gap percentages when fixed, equilibrium flows from the corresponding original network (the network before the urban rail is implemented) are applied to the equivalent modified network – as would be done in microsimulation. These values are consistently higher showcasing the limitation and potential error of microsimulation analysis.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost Gap Percentage</th>
<th>Cost Gap Percentage with Fixed Flows</th>
<th>Average Total Travel Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>1.1834</td>
<td>-</td>
<td>26.68</td>
</tr>
<tr>
<td>Worst Case</td>
<td>1.8185</td>
<td>1.9750</td>
<td>26.88</td>
</tr>
<tr>
<td>4% Scenario</td>
<td>1.4186</td>
<td>1.9286</td>
<td>27.34</td>
</tr>
<tr>
<td>8% Scenario</td>
<td>1.7122</td>
<td>2.4463</td>
<td>17.03</td>
</tr>
<tr>
<td>16% Scenario</td>
<td>0.6790</td>
<td>2.9367</td>
<td>20.61</td>
</tr>
</tbody>
</table>

TABLE 1  Convergence Measures and Average Travel Times
The average total travel time is heavily dependent on convergence and slight differences should not be viewed as significant. Therefore, the Base Case, Worst Case, and the 4% Scenario have essentially the same total system travel time (TSTT), while the 8% Scenario and 16% Scenario have considerably lower TSTT. The cost gap percentage is similar in value across all scenarios. Table 2 compares the average travel times (across the entire simulation period) of the major east-west corridors.

**TABLE 2 Average Travel Times on East/West Streets**

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Base Case</th>
<th>Worst Case</th>
<th>4% Scenario</th>
<th>8% Scenario</th>
<th>16% Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cesar Chavez EB</td>
<td>6.45</td>
<td>6.03</td>
<td>6.44</td>
<td>5.93</td>
<td>6.05</td>
</tr>
<tr>
<td>Cesar Chavez WB</td>
<td>7.81</td>
<td>7.77</td>
<td>7.77</td>
<td>7.98</td>
<td>7.28</td>
</tr>
<tr>
<td>5th Street</td>
<td>5.82</td>
<td>5.67</td>
<td>5.78</td>
<td>5.57</td>
<td>5.54</td>
</tr>
<tr>
<td>6th Street</td>
<td>6.44</td>
<td>6.44</td>
<td>6.44</td>
<td>6.64</td>
<td>6.65</td>
</tr>
<tr>
<td>8th Street WB</td>
<td>3.36</td>
<td>3.34</td>
<td>3.49</td>
<td>3.48</td>
<td>3.28</td>
</tr>
<tr>
<td>7th Street EB</td>
<td>3.78</td>
<td>3.80</td>
<td>3.79</td>
<td>3.79</td>
<td>3.76</td>
</tr>
<tr>
<td>9th Street EB</td>
<td>2.99</td>
<td>2.81</td>
<td>2.98</td>
<td>2.81</td>
<td>2.98</td>
</tr>
<tr>
<td>10th Street WB</td>
<td>3.45</td>
<td>3.64</td>
<td>3.49</td>
<td>3.46</td>
<td>3.46</td>
</tr>
<tr>
<td>11th Street EB</td>
<td>5.83</td>
<td>5.56</td>
<td>5.50</td>
<td>5.04</td>
<td>5.39</td>
</tr>
<tr>
<td>11th Street WB</td>
<td>4.88</td>
<td>5.05</td>
<td>5.19</td>
<td>5.00</td>
<td>4.84</td>
</tr>
<tr>
<td>12th Street EB</td>
<td>3.64</td>
<td>3.30</td>
<td>3.23</td>
<td>3.54</td>
<td>3.14</td>
</tr>
<tr>
<td>12th Street WB</td>
<td>2.88</td>
<td>2.84</td>
<td>2.87</td>
<td>2.86</td>
<td>2.84</td>
</tr>
<tr>
<td>15th Street WB</td>
<td>6.00</td>
<td>6.16</td>
<td>6.35</td>
<td>5.96</td>
<td>5.98</td>
</tr>
<tr>
<td>15th Street EB</td>
<td>11.40</td>
<td>8.86</td>
<td>17.21</td>
<td>6.41</td>
<td>6.34</td>
</tr>
<tr>
<td>M.L.K. Boulevard WB</td>
<td>4.21</td>
<td>4.34</td>
<td>4.19</td>
<td>4.30</td>
<td>3.99</td>
</tr>
<tr>
<td>M.L.K. Boulevard EB</td>
<td>3.60</td>
<td>3.50</td>
<td>3.56</td>
<td>3.60</td>
<td>3.61</td>
</tr>
</tbody>
</table>

As shown in Table 2, most of the east/west streets have roughly the same travel times across all scenarios. This makes intuitive sense since the majority of the urban rail runs in the north and south direction, and the significant changes to the existing transportation system occur along north/southbound streets. There are markedly lower travel times on eastbound 15th Street in the 8% Scenario and 16% Scenario. This occurs because 15th Street is a major arterial near one of the largest employers in Austin: the State Capitol. The travel times on major north-south corridors were also similar among the scenarios – even on the Guadalupe/Lavaca route where a lane drop occurred. This is shown in Figure 4.
As shown in Figure 4, travel times on the Guadalupe/Lavaca route are essentially the same across all scenarios. There are only slight increases in travel time in the Worst Case. The cyclic pattern of the Figure suggests free-flow traffic. Cycles occur because of timed traffic signals. If the route was congested, Figure 4 would show a single rising and falling peak (the typical peak period curve). The geometric changes to the transportation system are not causing significant impacts because Guadalupe and Lavaca are operating at free-flow speed (are not congested) even with the dropped lane. However, when one analyzes the more congested segments of the Guadalupe/Lavaca route, it is clear that travel patterns are changing among the scenarios. The congested segments only occur along Lavaca and are shown in Figure 5. They form the congested Lavaca corridor.

Figure 6 shows the average total volume on the congested Lavaca corridor. As shown in the Figure, there is significantly less traffic on the corridor in the urban rail scenarios compared to the Base Case. This suggests that users are switching their route away from Lavaca due to congestion from the transit system changes. It is important to note that Figure 6 exhibits the typical peak period pattern. This pattern is also observed in Figure 7, further suggesting that these links are indeed congested – especially in the Worst Case.
FIGURE 5 Parallel corridors near the congested segments of Lavaca.

FIGURE 6 Volume on congested Lavaca corridor for each scenario.
FIGURE 7 Congested Lavaca corridor travel times.

Based on analyzing all the paths from the origin and destination shown in Figure 5, in the Worst Case and 4% Scenario traffic on Lavaca shifts to other parallel corridors – increasing the volume on North Congress Avenue, Nueces, Rio Grande, and Trinity Streets. This is shown in Figure 8, where link flows are the total number of vehicles over the analysis period that use a path connecting the O-D pair in Figure 5. The path analysis of the 4% Scenario was virtually the same as the Worst Case. This specific O-D was chosen because it had the highest demand of drivers using the congested Lavaca corridor. In the 8% and 16% Scenarios, traffic on Lavaca increases, lowering the volume on N. Congress, Trinity, and Nueces. See Figure 9. This occurred because the large number of drivers switching to the urban rail eases congestion on Lavaca and its parallel corridors. These findings are confirmed with Figures 10 and 11, which show the volume on North Congress and Trinity Street Corridors. These corridors are shown in Figure 5. As shown in Figures 10 and 11, volume on N. Congress and Trinity are much higher in the Worst Case and 4% Scenario.
FIGURE 8 Comparison of travel patterns – the Before and Worst Case.

Before Case

Worst Case

Link Flows

- **1 - 10**
- **10 - 20**
- **20 - 30**
- **30 - 50**
- **50 - 100**
- **100 - 150**

If not specified, link flows are zero.

Significantly less traffic on Lavaca

Increased traffic on Nueces, Rio Grande, and Trinity.
FIGURE 9  Comparison of travel patterns – the Before Case and 8% Scenario

Lower traffic on N. Congress and Brazos.

Higher traffic on Lavaca.
FIGURE 10  Total average volume on the N. Congress Avenue Corridor.

FIGURE 11  Total average volume on the Trinity Street Corridor.
CONCLUSION

This paper showcased the benefits of using dynamic traffic assignment to model traffic impacts caused by the implementation of new transit facilities. DTA bridges the two previously researched analysis methods (microsimulation and regional planning) by retaining their advantages while addressing their shortcomings; it can model route choice behavior using detailed inputs at a fine time scale across a region-wide spatial area. The proposed urban rail system in Austin, TX was used as a case study. The analysis showed that the urban rail has little impact on the overall transportation system since the network exhibits minimal congestion at the locations where major detrimental changes occur. The few locations where congestion exists along the railway path indicate that travel patterns do change; if low ridership occurs, traffic in these areas will switch to parallel roadways.

DTA can not only be used to evaluate large-scale transit alternatives, it can be a useful tool in the design process. For example, DTA can be used to determine the location of transit stops so that the overall total system travel cost is minimized. DTA can also be used to conduct a sensitivity analysis of several estimated ridership levels. The integration of DTA into the design of transit systems provides limitless possibilities and the potential for more efficient systems. It is a topic worthy of further research.

ACKNOWLEDGEMENT

The authors would like to thank Jennifer Duthie and Natalia Ruiz Juri from the Network Modeling Center at the Center for Transportation Research for their guidance and for providing the calibrated base model.

REFERENCES


18. City of Austin Transportation Department and Capitol Metropolitan Transportation Authority. Austin Urban Rail Corridors: Central Austin Circulator – Long Center Spur and East Riverside ABIA. City of Austin, 2008.


