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16. Abstract

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CAN TRANSIT ORIENTED DEVELOPMENTS REDUCE AUSTIN'S TRAFFIC CONGESTION?

By

Ming Zhang

Chang Yi

Research Report SWUTC/06/167869-1

Southwest Regional University Transportation Center
Center for Transportation Research
University of Texas at Austin
Austin, TX 78712

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ABSTRACT

Transit-Oriented Development (TOD) is expected to generate a long list of benefits. Of which reducing car use and relieving traffic congestion are among the top. To what extent can TOD contribute to reduce regional congestion? This paper presents an empirical study of Austin, Texas where a new commuter rail line is under construction and TOD proposals are being developed. The study applied the four-step travel demand modeling to estimate regional travel outcome in one base scenario (No TOD) and two TOD scenarios for the year 2030. Scenario design considers Austin's TOD ordinance and the All-System-Go Long-Range Transit Plan. Results of the study confirm that TOD would have a great potential to improve regional travel, should it be fully implemented. The improvement is indicated by several measures. First, TOD is estimated to reduce daily PMT by 10-12 million in the region as a whole, or by 3.5-4.5 PMT per person. Second, VMT by the driving modes (SOV and SR) would drop by over 20% while travel by transit and walk/bike increases. The net VMT reduction ranges from 21-27% under the two TOD scenarios. Finally, resulting from TOD practice, the portion of congested roadway in the Austin region is estimated to reduce by 2.2 percentage points, or nearly 700 lane miles. These results provide strong evidence to support TOD practice.

EXECUTIVE SUMMARY

Voters in Austin, Texas gave the green light to the region's commuter rail plan in November 2004. This is a part of Austin's long-range transit plan called "All-Systems-Go." In light of this approval, transit-oriented development (TOD) as an integrated land use-transportation development strategy has gained momentum. In May 2005, the City of Austin adopted the TOD ordinance, providing practical guidance to implement TOD along the proposed rail line. Currently, selected planning and design firms are developing TOD proposals for areas around the rail transit stations.

TOD is expected to generate a long list of benefits. Of which reducing car use and relieving traffic congestion are among the top. The basic premise of TOD is that if we design our built environments conducive to alternative transportation modes to driving, the demands for automobile travel could be reduced. Indeed, by clustering commercial and office development with high-density residential use around transit stations, TOD may help decrease automobile dependence. Subsequently, TOD could then decrease region-wide traffic congestion by promoting walking, bicycling, and the use of public transit. In this sense, planners have praised TOD as a viable, long-term solution for traffic congestion. Calthorpe (1993) states, "reducing trip lengths, combining destinations, carpooling, walking, and biking are all enhanced by TODs," and TODs can "help relieve our dependence on the auto in many ways." (p.42) Daisa (2004) also describes TOD as "a key strategy being used by planning and transportation professionals to curb growth, reduce traffic congestion, provide transportation choice, and improve quality of life." (p.114) Many other researchers endorse this perspective on TOD (e.g., Cervero 1998; Newman and Kenworthy, 1999; Cervero et al., 2004).

Austin's development past and future trend calls for such tools as TOD to tackle with traffic consequences associated with the rapid growth. From 1990 to 2000 the U.S. Census records the growth of total population in the Austin metropolitan area from 781,572 to 1,159,836. By 2030, the region's population is projected to reach 2.75 million. Accompanying the population growth is the worsening traffic conditions. In the 2005 Urban Mobility Report from Texas Transportation Institute, Austin ranked 13th in terms of annual hours of delay per traveler among 85 U.S. metropolitan areas (TTI, 2005).

Can TOD reduce Austin's traffic congestion? If so, to what extent? While it may be unrealistic to expect the disappearance of congestion after TOD implementation, it is important to understand the extent to which the TOD initiative may help slow down Austin's congestion growth. Over-expectation of TOD's role may lead to inefficient use of land resources and misallocation of public funds, which would eventually cause political backfire. On the other hand, under-expectation of TOD would incur opportunity costs when TOD could offer potentials to significantly reduce driving and congestion. To our knowledge, no direct evidence has been reported with respect to the impact of TOD on region-wide traffic conditions.

The study in this report is designed to examine the above questions by modeling traffic outcomes under a number of TOD scenarios in the Austin region. Results of the exercise are expected to better inform the policy makers and the general public on the potential of TOD in curbing congestion growth. Such informing is essential to develop specific TOD strategies, and more importantly, to gain political support for successful implementation of TOD. Lessons learned from the study will also add to the knowledge base where there are currently more hopes than evidence on the role of TOD for congestion relief.

This document reports a study on the potential of TOD in affecting regional travel in the Austin, TX area. Applying the four-step travel demand modeling tools, the study forecasts work commute in the region for the Year 2030 under three scenarios, the Base or No TOD scenario, the Rail-Only TOD scenario, and the All-System-Go TOD scenario. Results of the study confirm that TOD would have a great potential to improve regional travel, should it be fully implemented. The improvement is indicated by several measures. First, TOD is estimated to reduce daily PMT by 10-12 million in the region as a whole, or by 3.5-4.5 PMT per person. Second, VMT by the driving modes (SOV and SR) would drop by over 20% while travel by transit and walk/bike increases. The net VMT reduction ranges from 21-27% under the two with-TOD scenarios. Finally, resulting from TOD practice, the portion of congested roadway in the Austin region is estimated to reduce by 2.2 percentage points, or nearly 700 lane miles. These results provide strong evidence to support TOD practice. What is critical is how TOD can be effectively implemented. This is of course a different topic of research.

Several limitations exist in this study, suggesting future directions for improvement. The study explores only one aspect of TOD, densification of population and employment. Effects of other TOD aspects such as mixed use and pedestrian friendly design were not included. The four-step models, which are initially developed mainly for highway-based travel analysis, are rather constrained in capturing the design quality of the built environment that also affects travel decisions. Another study limitation is that the traffic estimates reported here are for home-based work trips only. Inclusion of non-work trips in the analysis is important to have a full understanding of TOD effects on travel. Furthermore, the traffic assignment results are 24-hour daily average. For congestion evaluation, peak hour conditions should be the focus. This study did not perform peak-hour analyses due to lack of data on link-level peak hour capacities and hourly traffic distribution for the region.

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INTRODUCTION

On November 2, 2004, voters in Austin, Texas gave the green light to the region's commuter rail plan. This is a part of Austin's long-range transit plan called "All-Systems-Go." In light of this approval, transit-oriented development (TOD) as an integrated land use-transportation development strategy has gained momentum in Austin. In May 19, 2005, the City of Austin adopted the TOD ordinance, providing practical guidance to implement TOD along the proposed rail line. Currently, selected planning and design firms are developing TOD proposals for areas around the rail transit stations.

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The remainder of this report is organized as follows: the next section reviews related studies. It is then followed by the description of study method and TOD scenario design. Section 4 reports and interprets modeling results associated with each scenario. Finally, Section 5 summarizes analysis results and discusses limitations of study.

RELATED STUDIES

Conceptually, TOD refers to mixed-use, relatively intense development concentrated around the transit station in 4/1-1/2 radius and oriented to transit riders with pedestrian- and cycle-friendly environment. A variety of physical, financial, and regulatory tools exist for TOD implementation. For example, physical planners and urban designers have focused on densification, infill development, pedestrian-friendly environmental design, or generally known as the New Urbanist design vocabularies. It is expected that, in transit friendly neighborhoods, people would likely use the nearby transit systems more and drive less than in other places. Traffic conditions on the road would be better compared to when these people join the driving crowd.

So far, no direct evidence has been found with respect to the impact of TOD on reducing traffic congestion in the literature. While there are few studies that investigated the impact of TOD on traffic congestion, numerous researchers conducted studies to see if the land use characteristics of station area have influence on the transit ridership. Most of these studies investigating the relationship between transit ridership and TOD are conducted at station level.

Overall, the results indicate that high density, mixed-use and pedestrian-friendly urban design play major roles in increasing transit usage (Cervero, 1993; Cervero, 1994a; Parsons Brinckerhoff Quade & Douglass, 1995; Cervero, 1996; Parsons Brinckerhoff Quade & Douglass, 1996; Rosenbloom and Clifton, 1996; Ewing and Cervero, 2001; Cervero, 2002). Specifically, studies found that among 3Ds of urban form (density, diversity, and design), local density around transit stations plays a major role in increasing transit ridership (Cervero, 1993; Cervero, 1994a; Parsons Brinckerhoff Quade & Douglass, 1995; Parsons Brinckerhoff Quade & Douglass, 1996; Rosenbloom and Clifton, 1996; Pushkarev and Zupan, 1977; Cervero, 1994b; Holtzcraw, 1999; Holtzclaw, Dittmar, Goldstein, and Haas, 2002). Ewing and Cervero (2001) state, "transit use depends primarily on local densities." (p.92) Some studies found the significant impact of mixed land use and pedestrian-oriented design on transit ridership (Cervero, 1996; Cervero, 2002; McNally and Ryan, 1993; Filion, 2001). Overall, as Cervero et al. (2004) indicate, increased transit patronage is the single benefit of TOD that is widely agreed upon. Table 1 summarizes the results of the past research on this topic.

Table 1: TOD and Its Impacts on Ridership and VMT

TOD and Transit Ridership	Major Findings
Pushvarev and Zupan (1977)	In areas with more than 7 dwelling units per acre, transit use is much higher and auto use is much lower.
JHK & Associates (1987)	- Forty percent of residents living in the Washington D.C. Rosslyn-Ballston corridor use transit for commuting, while the regional transit ridership rate is about 10 percent. Also, more than 60 percent of D.C. metro riders living within a half mile from the corridor walked to stations. - More than half of the people who work within ¼ mile from metro stations in downtown Washington, D.C. use rail. - In suburban transit stations in Washington D.C. (e.g., Crystal City, Silver Spring stations), the transit share of workers is 16 to 19 percent.
Cervero (1993)	-More than 30 percent of residents living near Pleasant Hill station in the Bay Area Rapid Transit system commuted using BART compared to a citywide average of 16 percent. - More than half of those who moved to within one-half mile of a transit station switched from automobile to transit for commuting. - The level of ease in accessing transit station matters for ridership capture: at the San Francisco Center, that has direct portal connection to BART system, more than 30 percent of patrons arrived by transit. - Additional quarter mile increase from rail station decreases transit share by more than 60 % in Washington D.C. and 90 % in San Diego. - Additional 100 employees per acre increase transit trips by 2.2 percent. Density is a major factor contributing to transit ridership.
Cervero (1994a)	- The existence of rail component in suburban office complex increases transit commute share by 3 percent. - In the San Francisco Bay Area, people living near transit stations are six times more likely to commute with transit. - More than half of residents living near transit stations in Bay Area used to take transit before they moved into transit oriented developments. This is strong evidence of self selection. - Office space developed above rail station generated rail ridership. 10 percent increase in one rail station's share in office development in the whole region captures 1 percent of rail ridership in that station.
McNally and Ryan (1993)	Grid street pattern neighborhood has lower per capita VMT compared to conventional suburban street developments, assuming that trip generation rate is the same for the two types of developments.
Cervero (1994b)	- California employees working in offices within walking distance from BART stations are 2.5 times more likely to use transit to work compared to regionwide average. - Twenty percent of workers live and work near BART system commute by rail, while slightly more than 10 percent of employees far from BART system use transit.
Holtzclaw (1994)	- VMT decreases with increasing level of accessibility to transit stations. - In San Francisco Bay Area selected neighborhoods, if the population density increases by 100 percent, there is a 16 percent decrease in VMT per household.

Gerston & Associates (1995)	TOD residents in Santa Clara county are five times more likely to commute by transit than residents of the county.
Parsons Brinckerhoff Quade & Douglass (1995)	Doubling population density in station area leads 60 percent increase in transit ridership.
Cervero (1996)	- Mixed use transit hub at suburban employment center increase transit ridership by 5 to 10 percent on average. - The probability of taking transit increases with the presence of retail ships within 300 feet from one's residence
Parsons Brinckerhoff Quade & Douglass (1996)	Light rail ridership increases with total CBD employment and job density in CBD in selected cities.
Rosenbloom and Clifton (1996)	- Population density is the significant determinant of transit ridership at the metropolitan area level. - The higher the city size, the higher the overall transit ridership - Subway and light rail captures demand of high income transit choice riders, while the main riders of buses are low income travelers.
Bragado (1999)	At the Horton Plaza shopping center in San Diego which is located within walking distance from Trolly line, more than 60 percent of the shoppers arrive by transit.
Kain and Liu (1999)	Transit ridership increases with network expansion, fare reductions as well as growth in employment and population.
Holtzclaw (1999)	VMT generated from TOD residents is half of VMT from typical suburban subdivisions in the San Francisco Bay Area, controlling for socio-economic characteristics of the residents.
Ewing and Cervero (2001)	To increase transit ridership, local density is the primary factor and land use mix is the secondary factor.
Filion (2001)	Mixed land use suburban shopping centers were successful in increasing transit ridership.
Cervero (2002)	- Transit ridership increases with grid street pattern and pedestrian friendly urban designs around transit stations. - Higher degree of land use mix (measured by Entropy index) increases rail mode choice for all travel purposes.
Cervero and Duncan (2002)	- 20 percent of people living within half mile of rail stations commuted by rail. - Proximity to rail stations to workplaces was primary factor to choose residential location near rail stations. - With nested logit analysis, they found that selecting rail transit for commuting transportation mode was "nested" within choosing to live within half mile from rail stations or not. - About 40 percent of transit ridership is due to self-selection.
Holtzclaw et al. (2002)	Residential density has significant impact to reduce household automobile ownership and VMT per capita by more than 30 percent. Marginal impact of transit accessibility on automobile ownership is also found
Switzer (2002)	Approximately 20 percent to 60 percent of residents around rail transit stations in Washington D.C. take transit to work. Most of those travel to the District of Columbia.
Kuby et al. (2004)	One hundred additional employments within half mile from light rail stations increases 2.3 passengers on typical weekdays. And for every additional 100 population within walking distance to light rail stations, 9.2 more boardings are generated.

Ridership increase from TOD practice certainly benefits transit agencies, for example, by bringing more farebox revenue and improving service efficiency. However, even if ridership increases, it is still unclear whether traffic congestion will decrease as a result of implementing TOD. To the contrary, congestion may even increase in the station area, because successful TOD will make the station area a multi-functional place that would attract more people and traffic. The congestion relief effect of TOD, if any, is expected to happen at the regional level, if TOD can persuade motorists to drive less and ride on transit instead (Parsons Brinckerhoff Quade & Douglass, 1996). For this reason, empirical test of TOD's effect on roadway congestion ought to be conducted at the regional scale and across all travel modes. To our knowledge, this has not been studied by the research mentioned above.

Another issue is 'self-selection': Those who prefer transit-oriented life style may choose to live in the TOD area (Cervero, 1994a). In other words, TOD practice may lead to spatial sorting of households who have travel preferences into high-density residences in TODs. Yet there may be no behavioral changes in travel, hence no changes in total travel outcome. To precisely account for the TOD effects on travel, residential location decision and travel choice should be jointly considered, which requires a sophisticated tool as a large scale, integrated land use-transportation model. One example of the tool is the Portland LAUTRAQ model. TOD also includes a variety of financial and regulatory means to discourage car use. Examples include location efficient mortgage in the TOD district, modified parking codes, shared parking facilities, and TOD zoning. Detailed review of literature on these topics is omitted here because the study presented in this paper focuses on the physical aspects of TOD.

This study differs from those reviewed above in that it employs a full process of travel demand modeling in the effort to account for the effects of TOD on regional travel. Land use changes under different TOD scenarios are simulated with simplified population allocation procedures. Doing so reduces the needs for immense resources and time that are typically required for calibrating large scale land use-transportation models. Descriptions of the study method follow.

METHODOLOGY

TOD Scenarios

To examine the potential impacts of TOD on Austin's traffic congestion, we apply the four-step transportation models to estimate travel demand in the Austin region in the year 2030. Results of the models would indicate Austin's traffic condition in 2030 without implementing any TODs. This is the base scenario for our study. Next, we repeat the modeling exercises for the following two scenarios:

1) There are ten TODs around the proposed commuter rail stations;
2) In addition to the ten rail-based TODs, bus-based TODs will also be developed in smaller scales along the local and express bus routes designated in the All- Systems-Go long range plan.

The differences in traffic flows between the base and the two other scenarios indicate the effects of TOD on roadway conditions. TOD attributes in the above scenarios are specified according to Austin's TOD ordinance (City of Austin, 2005) and All-Systems-Go plan developed by Capital Area Metropolitan Planning Organization (CAMPO), which is the Metropolitan Planning Organization (MPO) of the Austin region. The TOD ordinance specifies average land use density, building heights, and appropriate land use mix for commuter rail station areas. The development characteristics established in the ordinance are intended to support the use of public transit, walking and bicycling (City of Austin, 2005). In the ordinance, the City of Austin has established four different types of TOD districts that would be developed in accordance with the existing characteristics of the station areas. These are Neighborhood Center TOD, Town Center TOD, Regional Center TOD, and Downtown TOD. Land use densities vary among these types of TOD. Table 2 below presents characteristics of each type of TOD and indicates the TOD district types for the proposed commuter rail stations.

Table 2: Austin TOD Typology

TOD Type	Average Density	Building Height	Land Uses	Austin Station
Neighborhood Center TOD	15-25 units per acre	1-6 stories	Small lot single family, townhomes, low-rise condo, apartments, neighborhood retail and office	- Plaza Saltillo - MLK Jr Blvd - Lamar Blvd - Howard Lane - Highland Mall - McNeil
Town Center TOD	25-50 units per acre	2-8 stories	Townhomes, low and mid-rise condo, apartments, retail and office, mixed use buildings	- Northwest Park and Ride - Pickle Research Center
Regional Center TOD	More than 50 units per acre	3 to 10 stories	Mid-rise condo, apartments, major retail and office, and mixed use buildings	
Downtown TOD	More than 75 units per acre	More than 6 stories	Mid and high-rise condo, apartments, large retail and office, and mixed use buildings	- Convention Center

Adopted from Austin TOD Ordinance

Each TOD district is then divided into three zones: Gateway Zone, Midway Zone, and Transition Zone. Each zone has designated intensity and scope of development. The development intensity is higher for zones closer to the rail station platform. The parking regulations and requirements are also stated in the ordinance. These include; 1) parking prohibited in the area between the front line and the building with a front yard setback of 15 feet or less; 2) if a rear parking is larger than three acres, the parking lot must be designed to permit future driveway and sidewalk connections; and 3) 60 percent of parking needs to be off-street parking. Table 3 summarizes the characteristics of these zones.

Table 3: Characteristics of Austin TOD Zones

Zone	Area	Characteristics
Gateway Zone	The area that immediately surrounds the station platform, 300-500 feet from the edge of the station	- Density is highest in the TOD district. Highest level of transit integration with streetscapes - Provide good connections between the station and surrounding land uses. - Provides ground floor pedestrian-oriented retail and office uses.
Midway Zone	The area between gateway zone and transition zone	- Primarily residential with retail and office. - Density and building height lower than in a gateway zone but higher than in a transition zone.
Transition Zone	The area at the periphery of the TOD district	- Primarily residential with retail and office. - Lowest density in the TOD district. - Development intensity is compatible with existing or future development outside of the TOD district.

In the All-Systems-Go plan, the existing bus service would be improved and extended with higher speed, new information technologies, priorities for bus to use High Occupancy Vehicle (HOV) lanes, and new park and ride locations. To provide connections to different transit services, special shuttles would transport transit riders to and from rail stations. According to the plan, express bus service starts in 2007, and commuter rail start operating in 2008 (CAMPO, 2006).

Land Use Changes under Different TOD Scenarios

Under each of the two different TOD scenarios, population and employment are redistributed across the Austin region. The following two equations describe the method used to project populations and jobs around TODs (Zhang, et al. 1999).

$$G = \sum_i g_i = \sum_i a_i * D * H$$

where,

G: Total population or employment gains in TOD areas

i: Traffic Analysis Zone (TAZ)

g_i: Population or employment gains in TAZi that is overlapped with quarter mile buffer around station areas

a_i: Area of TAZi that falls within quarter mile buffer areas from rail stations

D: Population and employment density (units per acre)

H: Average household size or median number of workers in household in TAZ i

$$m_i = G * \frac{(p_i^1 - p_i^0)}{\sum_i (p_i^1 - p_i^0)} \text{ for all i not in station areas}$$

where,

G: Total population or employment gains in TOD areas

i: Traffic Analysis Zone

m_i: Population or employments loss in TAZi for all TAZs not overlapped with quarter mile buffers from rail stations

p^0_i: Total population or employments in TAZi in 1997 (projection base year)

p^1_i: Total population or employments in TAZi in 2030

The method employed here implies three underlying assumptions. First, no additional growth would result from establishing commuter rails or extending bus routes besides the growth in population and jobs forecasted by CAMPO. CAMPO offers population and employment projection for 2030 based on 1997 survey. Second, population and employments would be redistributed to the density levels specified in Austin's TOD ordinance. This may not be exactly the case in the real world since location decisions of households and firms are dependent upon various regional attributes in addition to the transportation system (Zhang et al., 1999). Third and finally, due to limitations in data sources, we assume that the socio-economic characteristics of the population in 2030 will not change from the base year, even though this is highly unlikely.

For our analyses, population and employment densities are specified for the rail-based TOD areas at the minimum density levels designated in the Austin TOD ordinance (Table 2). The employment densities are assumed to increase by two thirds that of the population densities. The Austin TOD ordinance does not have the density provision for bus-based TOD in the All-Systems-Go TOD scenario. In this study, we assume that the quarter-mile buffer along the express bus routes (not stations) would be developed to two times the density level of the projected zonal population and employment in Year 2030[1]. Along the local bus lines, population and employment densities are lower than those along the express bus routes. The densities are accordingly assumed to be 1.5 times the 2030 density level. Table 4 shows the population and employment densities designated for the TOD areas for the 2030 base year and for the bus-based scenario. Figure 1 illustrates major transit corridors in the Austin area.

[1] We use buffer areas from bus routes instead of stations in delineating future TODs, because the stations are not yet planned in All-Systems-Go plan. Nonetheless, considering that interval between bus stations is approximately a quarter-mile or less in Austin, the extent of TODs in this study would be similar to those that would be created by buffer area from stations.

Table 4: Minimum Population and Employment Densities for TOD Scenarios

	2030 Population Density (Units/Acre)	2030 Employment Density (Units/Acre)	Express Bus TOD Population Density	Express Bus TOD Employment Density	Local Bus TOD Population Density	Local Bus TOD Employment Density
Below Riverside Drive	3.5	10.8	7.0	20.2	5.3	16.2
Downtown (Riverside–MLK)	3.7	9.6	7.4	19.2	5.6	14.4
MLK – US290/183 Corridor	3.8	7.9	7.6	15.8	5.7	11.9
Beyond US 290/183 Corridor	2.6	3.4	5.2	6.8	3.9	5.1

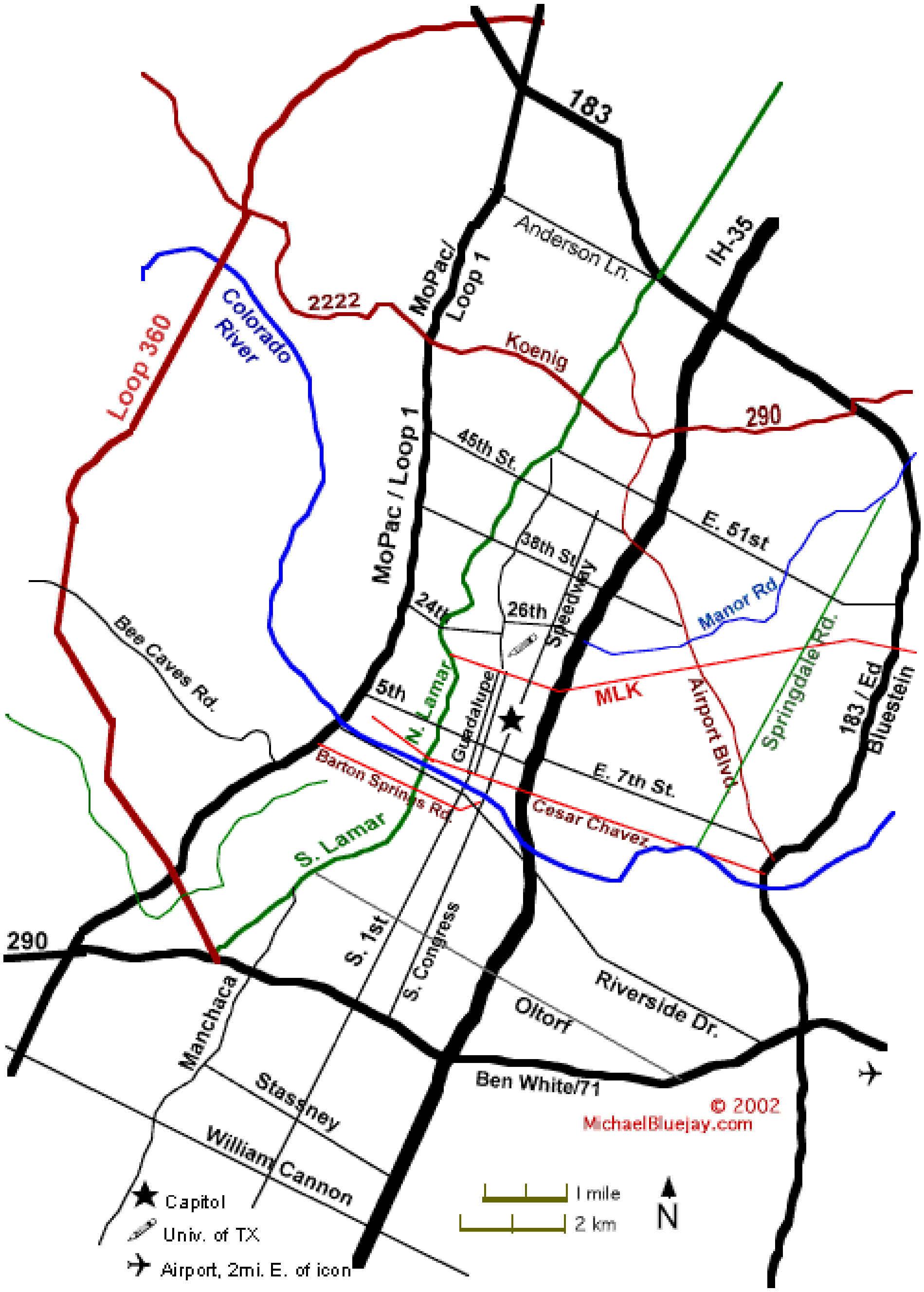

Figure 1: Major Corridors in Austin Metropolitan Areas
(source: michaelbluejay.com/austin/map-big.gif)

Travel Demand Modeling

Standard procedures of the four-step travel demand modeling are followed to estimate Austin's regional travel demand in each of the three TOD scenarios. Below details each of the four steps applied to the Austin case.

Step 1: Trip Generation

Trip generation is the starting point of the four step travel demand modeling. This is the process to estimate how many trips would be generated in the study region. Trip generation stage can be further divided into two steps: trip productions and attractions. First, we divide the study region into Traffic Analysis Zones (TAZ) that are the units of analysis in travel demand modeling. Then, we estimate how many trips will be produced from each TAZ; in other words, we predict how many persons would start their trips from each TAZ. According to CAMPO, the number of trips produced from each zone is a function of the average household size, the median family income level, and the median number of workers in households of each TAZ. Different average trip production rates, provided by CAMPO, are applied to TAZ data for trip productions (CAMPO, 2000).

Based on trip production results, we estimate trip attractions. This is to predict how many of the produced trips from TAZs would be attracted to all the other TAZs in the area[2]. For this step, TAZs are classified into Central Business Districts (CBD), CBD fringe, Urban, Suburban and Rural areas. And different trip attraction rates are applied to the different types of TAZs based on the number of households, the number of basic retail services, and the educational employments contained in each TAZ. After the trip attraction step is completed, we assume that all the trips produced within the region are headed to destinations within the same region. That would mean that the total number of trips produced should be the same as the total number of trips attracted. We simply scale up or down either one of productions and attractions; this is called trip balancing. The final result of trip generation step is balanced trip table that indicates number of trips produced and attracted to each TAZ.

Step 2: Trip Distribution

In this step, trips produced from and attracted to each TAZ are distributed as trip pairs across the 1,117 TAZs in the region. This procedure typically applies a gravity model, estimating spatial interactions as a function of travel time. Based on the link-level travel times provided by CAMPO, a travel time matrix (i.e., skim table) is derived for each travel mode. Furthermore, a friction function (shown below) is calibrated to capture the sensitivity of Austin traveler to the increase in trip length (time).

$$f(d_{ij}) = e^{-c}, c > 0$$

where,

d_{ij} = travel time between TAZ_i and TAZ_j

c = 2.16598 estimated coefficient for sensitivity to travel time for home-based work trips

Using the equation above, we then distribute trips from TAZ to TAZ according to the following gravity-based model.

[2] There would be internal trips that originate from a zone and end in the same zone.

$$T_{ij} = a_i * P_i * b_j * A_j f(d_{ij})$$

where,

T_{ij} = the forecast flow produced by zone i and attracted to zone j

P_i = the forecast number of trips produced by zone i

A_j = the forecasted number of trips attracted to zone j

a_i = the balancing factor for row i

b_j = the balancing factor for column j

Step 3: Mode Choice Modeling and Modal Share Forecasting

The next step is to estimate shares of travel by different modes. A multinomial discrete choice model is estimated with the use of 1,975 sample points from the 1997 Austin Travel Survey. Travel options available in the region were aggregated into four major modes: Single-Occupant Vehicle (SOV), Shared-Ride (SR), Transit and Walking/Biking (WB). The coefficients obtained from this model are then applied to the same variables specific to TAZ data to forecast modal share of SOV, SR, bus and walking/biking of TAZ trip pairs.

Step 4: Trip Assignments

From the previous step, after the coefficients from the mode choice model are applied to each TAZ trip pair, we obtain matrices for number of trips distributed between TAZs specific to a mode; SOV, SR, bus, and walk/biking. In this step, as the last stage of four step travel demand modeling, TAZ trip pairs are assigned to street system of the Austin area. The User Equilibrium Method was used for this part of modeling work. It follows an iterative process to achieve a convergent solution, in which, once routes are assigned for each traveler, no traveler can improve their travel times by shifting routes. In each iteration, network link flows are computed that incorporate link capacity restraint effects and flow-dependent travel times provided by CAMPO for the year 2030. Final results would indicate traffic flow and travel time in each direction and total amount of traffics assigned to all street segments in the study area.

The link level travel times used for four step travel demand estimation are given for the year 2030 without considering TODs. However, after population and employment densities are modified according to TOD scenarios, travel time at each street segment would be different from what is initially given for 2030. Thus, through the four steps above, once the new travel times at each link are obtained from the trip assignment stage, we update our travel time information developed for driving, bus and walking/biking. Then, the four steps are repeated for TOD scenarios using the updated travel times. Comparing traffic volume and capacity on roadway from trip assignment step, we would be able to see the level of traffic congestion in every street segment in each TOD scenario.

RESULTS

All of the above steps of the modeling were performed in TransCAD GIS, except for the mode choice model, which was estimated externally. The final model consisting of a set of variable coefficients was then imported to TransCAD. This section reports the estimated effects of TOD in the Austin area on travel outcome in terms of modal split, person miles of travel, vehicle miles of travel, and roadway performance/congestion conditions.

TOD Effects on Modal Split

Modal split is the essential part of this study. Table 5 reports the results of mode choice modeling. Travel demand theories suggest that traveler individual characteristics, e.g., age, gender, and race should have influence on decisions of travel mode choice. However, they were not statistically significant in the Austin model, and therefore were excluded from the final model used for TOD scenario-based forecasting. Aside from the mode specific constants, the final model shown in Table 5 contains three sets of explanatory variables. The first set includes such variables as travel times and monetary costs that characterize modal performance. They are also typical policy variables as public policies affect both time and costs of travel (e.g., through capacity expansion and toll or fare collection). Both travel time and cost coefficients display the expected negative sign and are statistically significant.

The second set of variables describes traveler household characteristics. They include number of vehicles in the household, household income, and household size, all specified to the driving modes. The third set of variables is the focus of this study: population and employment densities at trip origins and destinations. TOD practice alters their values and in turn changes travel outcome. They are all specified to the transit mode. The positive sign of the coefficient suggests that, when density increases, probability of riding on the transit increases as well.

Table 5: Mode Choice Model Results

Independent Variables (Modes to which the variable is specified)	**Coefficient**		**Standard Error**	**t-Statistic**
Transit Constant	-0.9926	**	0.3393	-2.93
SR Constant	-1.7118	**	0.4540	-3.77
SOV Constant	0.5766		0.4379	1.32
Travel Time (generic to all modes)	-0.0222	**	0.0065	-3.39
Travel Cost (generic to all modes)	-0.1144	**	0.0465	-2.46
# of Vehicles in Household (SOV, SR)	1.6336	**	0.2216	7.37
Household Income (in US$5,000's; SOV, SR)	0.1610	**	0.0450	3.58
# of Persons in Household (SOV, SR)	-0.2310	**	0.0879	-2.63
Population Density at Origin (persons/acre; Transit)	0.0848	**	0.0240	3.53
Population Density at Destination (persons/acre; Transit)	0.0698	**	0.0158	4.42
Job Density at Origin (jobs/acre; Transit)	0.0114	*	0.0069	1.65
Job Density at Destination (jobs/acre; Transit)	0.0055	**	0.0023	2.42

Auxiliary Statistics	at convergence	initial
Log Likelihood	-787.04	-2737.9
Number of Observations	1975	
Percent Correctly Predicted	89.06	

** Significant at 0.05 level
* Significant at 0.1 level
Dependent variable and sample shares: Single Occupant Vehicle (SOV; 88.6%), Shared-Ride (SR; 7.2%), Transit (TR; 2.5%.), and Walking/Biking (WB; 1.7%)

The estimated choice mode shown in Table 5 is used to forecast modal shares in the three TOD scenarios. Table 6 reports the estimated arithmetic averages of the mode choice probabilities. The average probability of choosing the SOV mode decreases from 91.04% in the base (No TOD) scenario to 90.56% in the rail-only TOD scenario, and to 90.24% in the All-Systems-Go TOD scenario. Similar trend is observed for the SR mode. As expected, the transit share increases as TOD is implemented from rail-only to the All-System-Go level. Overall, modal shifts are relatively small in magnitude. The result suggests the limited influence of land use-alone on travel mode choice, a finding reported by many other empirical studies (e.g., Zhang, 2004).

Table 6: Average Probabilities of Travel Modes in TOD Scenarios

	No TOD	Rail-only TOD	All-Systems-Go TOD
SOV	91.04%	90.56%	90.24%
SR	4.51%	4.48%	4.46%
Transit	4.10%	4.62%	4.97%
Walk/Biking	0.34%	0.34%	0.33%
SUM	100%	100%	100%

TOD Effects on Person Miles of Travel (PMT)

Outcome from the final step, i.e., traffic assignment, of the four-step travel demand modeling gives person-traffic flows on each roadway link in a typical work day in the study area. Multiplying the person flow with the link length (in miles) provides an estimate of mobility in terms of person miles of travel (PMT). Table 7 reports in the top section estimated PMT by each mode for the Base (or No TOD) scenario. To help assess the outcome, PMT per person is calculated with the projected population of 2.75 million in Year 2030 in the region. The calculation indicates an average of 16.63 daily PMT per person. This figure is slightly higher than the survey finding from the 2001 National Household Travel Survey (NHTS), which reports an average of 13.8 daily PMT per person (Ithaca MPO 2006). Our higher than NHTS PMT estimate is reasonable because personal travel in general grows over time.

Table 7: Comparison of Person-Miles-of-Travel
between the Base Scenario and the TOD Scenarios

Scenario #1: Base (No TOD)						
Travel Mode	**PMT**	**PMT / Person**				
SOV	43018340	15.64				
SR	2429201	0.88				
TRANSIT	243700	0.09				
WK	38605	0.01				
Total	45729847	16.63				
Scenario #2: Rail-Only TOD			**Change from Scenario #1**			
Travel Mode			**ΔPMT**	**ΔPMT /Person**		
SOV	33444384	12.16	-9573956	-3.481		
SR	2048195	0.74	-381006	-0.139		
TRANSIT	394930	0.14	151230	0.055		
WK	42265	0.02	3660	0.001		
Total	35929774	13.06	-9800073	-3.563		
Scenario #3: All-System-Go TOD					**Change from Scenario #2**	
Travel Mode					**ΔPMT**	**ΔPMT /Person**
SOV	30616150	11.13	-12402190	-4.509	-2828234	-1.028
SR	1967201	0.72	-462000	-0.168	-80994	-0.029
TRANSIT	647511	0.24	403812	0.147	252582	0.092
WK	46321	0.02	7716	0.003	4057	0.001
Total	33277184	12.10	-12452663	-4.528	-2652590	-0.964

PCE: Passenger Car Equivalent. 1 Bus = 1.5 PCE.

The middle and the bottom section of Table 7 report PMT estimates for the two TOD scenarios. Also reported are changes in PMT between each of the TOD scenarios and the Base scenario. In the Rail-Only TOD scenario, PMT by the driving modes (SOV and SR) decrease from the Base scenario, whereas PMT by transit and walking/biking increase. The net change indicates a total reduction of 9.8 million PMT daily, of which 9.57 million PMT results from less SOV commute. One a per person basis, daily work commute potentially reduces by 3.56 miles in association with the rail-based TOD initiative.

The All-System-Go TOD scenario suggests a daily reduction of 12.4 million PMT, or 4.53 miles decrease per person in daily commute. Figures reported in the far right column in Table 7 show the PMT differences between the rail-only and the All-System-Go TOD scenarios. Because the All-System-Go plan includes the rail transit, these PMT differences can be attributed to the bus-based TOD. Specifically, of the total 12.4 million PMT reductions in the All-System-

Go TOD scenario, 2.65 million, or 21.3% are accounted by the bus-based TOD practice.

TOD Effects on Vehicle-Miles of Travel (VMT)

VMT measures mobility associated with the motorized modes, i.e., SOV, SR, and Transit for our study. It is the basis for many post-modeling analysis, for example, in estimating vehicle emissions for the purposes of environmental quality monitoring and analyses. Table 8 reports VMT estimates under the three TOD scenarios, excluding the WK mode. The reporting format is similar to Table 7 above. In calculating VMT, all modes are converted to the Passenger Car Equivalent (PCE) units. For the SR mode, an average occupancy of 2.5 persons is assumed. Results in Table 8 show similar TOD effects to those on PMT. For instance, the rail-only TOD scenario is associated with 9.5 million reductions daily in total VMT. This is 21.4% less than in the Base or No TOD scenario. VMT by SOV and SR decrease by 22.3% and 15.7%, respectively, while VMT by transit increase by 62.1%. Transit share remains small though.

In the All-System-Go TOD scenario, the total VMT reduction amounts approximately 12 million daily, a 27% drop from the base scenario. Of which 7.1% is attributable to the bus-based TOD.

Table 8: Comparison of Vehicle-Miles-of-Travel
between the Base Scenario and the TOD Scenarios

Scenario #1: Base (No TOD)						
Travel Mode	**VMT**	**Share**				
SOV	43018340	96.99%				
SR	971681	2.19%				
TRANSIT	365550	0.82%				
PCE Total	44355571	100%				
Scenario #2: Rail-Only TOD			**Change from Scenario #1**			
Travel Mode	**VMT**	**Share**	**ΔVMT**	**Percent**		
SOV	33444384	95.95%	-9573956	-22.3%		
SR	819278	2.35%	-152402	-15.7%		
TRANSIT	592395	1.70%	226845	62.1%		
PCE Total	34856057	100%	-9499514	-21.4%		
Scenario #3: All-System-Go TOD					**Change from Scenario #2**	
Travel Mode	**VMT**	**Share**	**ΔVMT**	**Percent**	**ΔVMT**	**Percent**
SOV	30616150	94.57%	-12402190	-28.8%	-2828234	-8.5%
SR	786880	2.43%	-184800	-19.0%	-32398	-4.0%
TRANSIT	971267	3.00%	605717	165.7%	378872	64.0%
PCE Total	32374298	100%	-11981273	-27.0%	-2481759	-7.1%

PCE: Passenger Car Equivalent. 1 Bus = 1.5 PCE.

TOD Effects on Roadway Performance/Congestion Conditions

We apply the conventional, Level-of-Service (LOS)-based method to evaluate roadway performance/congestion conditions for the three TOD scenarios. For each scenario, a number of calculations are carried out. First, a volume-to-capacity ratio (VC Ratio) is calculated for each roadway link in the study area using the traffic assignment output. Next, a letter, from A to E, is assigned to each link based on the VC Ratios, representing different LOS. Links are categorized based on their LOS letters with the cut-off points for LOS classification following those used in the TxDOT congestion study for the Austin region (Lomax, 2005). Finally, lane-miles (number of lanes of a link multiplied by the length of the link) are totaled under each LOS category. Results are reported in Table 9.

It is shown that most of roadway links are in non-congested conditions. The TOD effects on congestion are indicated in the number of total roadway lane-miles falling into the category of LOS E, or a VC Ratio of 0.9 and higher. It is a typical threshold used by the Highway Capacity Manual for categorizing a roadway as being congested. Based on this evaluation, 22.21% of the roadway (measured in lane-miles) in the Austin area is under congested condition in the base 2030 scenario. If the rail-based TOD is implemented, the share of congested roadway decreases to 19.66%. If TOD is practiced in all potential All-System-Go sites, congested roadway reduces further to 18.99%.

Table 9: Roadway Performance under TOD Scenarios

Volume-to-Capacity Ratio	Roadway Lane Miles in LOS Category under TOD Scenarios			
	Base	**Rail-Only**	**All-System-Go**	**LOS**
0-0.65	16176.42	16675.36	16804.40	**A**
0.65-0.73	259.79	299.49	272.85	**B**
0.73-0.82	285.00	312.84	257.03	**C**
0.82-0.9	186.40	175.02	272.42	**D**
0.9+	4827.50	4272.40	4128.41	**E**
Total	21735.11	21735.11	21735.11	
Congested (LOS = E or worse)	22.21%	19.66%	18.99%	

CONCLUSIONS

This document reports a study on the potential of TOD in affecting regional travel in the Austin, TX area. Applying the four-step travel demand modeling tools, the study forecasts work commute in the region for the Year 2030 under three scenarios, the Base or No TOD scenario, the Rail-Only TOD scenario, and the All-System-Go TOD scenario. Results of the study confirm that TOD would have a great potential to improve regional travel, should it be fully implemented. The improvement is indicated by several measures. First, TOD is estimated to reduce daily PMT by 10-12 million in the region as a whole, or by 3.5-4.5 PMT per person. Second, VMT by the driving modes (SOV and SR) would drop by over 20% while travel by transit and walk/bike increases. The net VMT reductions range from 21% to 27% under the two with-TOD scenarios. Finally, resulting from TOD practice, the portion of congested roadway in the Austin region is estimated to reduce by 2.2 percentage points, or nearly 700 lane miles. These results provide strong evidence to support TOD practice. What is critical is how TOD can be effectively implemented. This is, of course, a different topic of research.

Several limitations exist in this study, suggesting future directions for improvement. The study explores only one aspect of TOD, densification of population and employment. Effects of other TOD aspects, such as mixed use and pedestrian friendly design, were not included. The four-step models, which are initially developed mainly for highway-based travel analysis, are rather constrained in capturing the design quality of the built environment that also affects travel decisions. Another study limitation is that the traffic estimates reported here are for home-based work trips only. Inclusion of non-work trips in the analysis is important to have a full understanding of TOD effects on travel. Furthermore, the traffic assignment results are 24-hour daily averages. For congestion evaluation, peak hour conditions should be the focus. This study did not perform peak-hour analyses due to lack of data on link-level peak hour capacities and hourly traffic distribution for the region.

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