Variations in Toll Road Impacts:
Case Studies from Texas

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Facing funding shortfalls for infrastructure construction and maintenance, many urban regions are seeking to develop new toll roads. These can diversely impact a region's traffic, land use, economy and citizens' welfare. Regions have distinct network configurations, spatial and temporal variation in demand patterns, as well as road user characteristics affecting their response to such roads. This paper illuminates the nature of variations in impacts by consistently modeling and comparing the effects of adding toll roads to three distinct Texas regions with geographical proximity: Austin, Dallas-Fort Worth (DFW) and El Paso. Initial models were calibrated for the Austin region and then appropriately adapted to the DFW and El Paso regions. While impacts varied by region, all cases suggested impacts were greatest near the toll roads, with welfare improvements falling with distance in DFW and El Paso and toll road end points gaining the most in Austin.

INTRODUCTION

Roads arguably are the lifelines of most economies. Fast, reliable roads that efficiently move people and goods are vital for sustaining populations and their economic development. Over the years, many urban areas in the United States and around the world have grappled with growing demands on their road infrastructure. In the United States, the need for capacity expansion has increased enormously. U.S. commuters consistently rank traffic among the top three most significant regional policy issues together with the economy, education, and/or crime. (See, e.g., Scheibal 2002, Fimrite 2002 and Knickerbocker 2000.) Across the board, shortfalls in funding for road construction and maintenance have meant that federal, state and local governments are now looking at new methods of infrastructure financing. Toll financing is fast emerging as a viable mechanism for building roads faster than otherwise possible. Advances in electronic toll collection (ETC) technologies and increased public acceptance have aided the cause of toll roads; and public-private partnerships are evolving to build, finance, operate, own and maintain highway infrastructure (FHWA 2003). As of December 2007, there were almost 5,000 centerline miles of tolled roads, and 100 centerline miles of tolled bridges and tunnels in the United States, with roughly 3,000 of these centerline miles in the Interstate system (FHWA 2007).

Though toll roads may mitigate infrastructure limitations, they can have diverse impacts on a region's traffic, land use, economy and welfare. Toll roads are not without controversy and can be mired in political debate, as in Austin, where public resistance to various elements of toll road plans has surfaced (ABJ 2004). While some toll road projects are enormous successes, others have been perceived as notable failures, such as Germany's toll roads, the Dulles Greenway, Greenville Southern Connector, northern Tampa's toll roads (TRN 2003a) and Texas's Camino-Columbia tollway (TRN 2003b). All these aspects underscore the need to carefully model, study and analyze the impacts of adding toll roads to a region's network.

It is rather critical that one predicts and analyzes the impacts of proposed toll roads before selecting projects for implementation. Like many other transportation policies, toll roads can be expected to affect traffic flows and speeds, employment and household locations, economic activity, home values and traveler welfare in the region (see, e.g., LRC 1971, and Shanis et al. 1985). Different regions have distinct network configurations, spatial and temporal variations in demand and road user characteristics. These differences govern a region's response to toll roads, and thereby determine the actual nature of impacts.

This paper illustrates impact variations by consistently forecasting and comparing the effects of added toll roads in three distinct regions of Texas: Austin, Dallas-Fort Worth (DFW) and El Paso. These areas differ considerably, in size, demographics, traffic patterns and the extent of their existing toll road networks. While DFW is a large metropolitan area with an existing network of tolled roads, Austin is an expanding, medium-sized congested region with a variety of recently added tolled roads. El Paso is the smallest of the three, with a relatively short toll road planned for 2015. Given the variety of contexts and toll road plans, impacts are expected to vary, offering some lessons about traveler response and transport policies.

METHODOLOGY

The methodology adopted examines each of the three regions using a common modeling framework for traveler response to different scenarios. Behaviorally consistent techniques anticipate traffic and welfare impacts on roads adjoining added toll roads, bordering areas and entire regions. Travel demand models (TDMs) are run in a feedback arrangement with network assignment for equilibration of travel times and demand patterns. Kalmanje and Kockelman (2004) calibrated initial TDMs for the Austin region, and these were adapted to the DFW and El Paso regions. Challenges to adapting one region's model parameters to another, are discussed in the following sections.

The TDMs employed here consist of trip generation, destination choice, mode choice and departure time choice models for four trip purposes. When placed in a feedback loop with the traffic assignment model, the system converges to produce estimates of travel times, costs and flows on the network. Based on these estimates, various measures of toll road impacts are computed (such as local and regional travel speeds, revenue collections and welfare distributions). Impacts on link flows, trip attractions and mode shares are all examined and compared across the three study regions.

While behavioral models destination, mode and departure time choices were calibrated for the Austin region, preferences for travel time, cost and attractiveness factors are assumed identical across all three regions, given their geographic proximity. However, the models applied in each region differ in terms of their alternative specific constants (for mode and departure time), in order to ensure that marginal count totals are met (from locally obtained travel survey data). Moreover, somewhat different values of travel time were used to assign travelers to their respective network routes ($10 per vehicle-hour in DFW and $8 in Austin and El Paso). Also, different departure periods (peak versus off-peak, for example) were specified in the three regions based on current MPO practices and/or review of trip timing from travel survey data. Finally, trip productions (and attractions) were provided by each of the MPOs, so there was no need to transfer parameters for trip generation. As a result of all this, the TDMs are highly similar across the three regions, yet distinct in several fundamental ways.

DATA DESCRIPTION

Austin Region

Kalmanje and Kockelman's (2004) primary data source for calibrating the Austin TDM (and thus the TDMs used in the other two regions) is the 1998-1999 Austin (Household) Travel Survey (CAMPO 1997) conducted by the Capital Area Metropolitan Planning Organization (CAMPO 2000 and 2001). CAMPO also provided peak and off-peak travel times for each pair of the 1,074 traffic analysis zones (TAZs) in the three-county Austin metropolitan planning region. CAMPO's (1997) zonal demographic files provided information by TAZ on population, jobs (by basic, retail and service sectors[1]), special trip attractors and median household income. The U.S. census data provided information on vehicle ownership and income for calibrating the trip generation models. Krishnamurthy and Kockelman's (2003) Disaggregate Residential Allocation Model and

Employment Allocation Model (DRAM, EMPAL) were used in conjunction with the Austin TDMs to forecast the 2007 base year employment and household distributions for Austin. Kalmanje and Kockelman (2004) provide more details on the Austin data used for calibration.

The CAMPO year-2007 network file of 11,827 lane miles was used for this study. The Austin 2007 network includes 489 lane-miles of tolled roads, or 4.13% of Austin's total (coded) lane miles. These include State Highway 130 (a relief route for Interstate Highway 35) and extensions on Mopac (Loop 1 North) – US 183 North and SH 45 (North and South). A single toll of 15¢/mile was assumed, closely approximating actual tolls (which are subject to change).

Dallas-Fort Worth Metroplex

The North Central Texas Council of Governments (NCTCOG) provided household travel surveys from 1996 for the DFW region, along with zonal demographic files[2] and network data. NCTCOG also provided travel time estimates between all origin-destination zone pairs (by automobile and transit), trip production data, truck trips and external (entry/exit) station[3] traffic counts from their 1999 and 2007 model runs. There are 4,813 traffic zones and 61 external (entry/exit) stations in the DFW planning region.

DFW received the first of several new toll roads in December 1999. These new toll roads are the President George Bush Turnpike (PGBT), SH121, SH161 and IH30 high-occupancy vehicle (HOV) lanes. The Dallas North Tollway (DNT), International Parkway, Mountain Creek Lake Boulevard (MCLB) and Addison Airport Tunnel (AAT) have been around for quite some time, and thus were not considered "new" in the analysis; they are included in the existing network (and are tolled). Since NCTCOG's 1999 network includes only the DNT, AAT and MCLB links, the 2007 DFW road network (31,121 coded lane miles) is used for this study.[4] However, the TDM year is still considered to be 1999, since that is the year for which all population and employment (production and attraction) inputs are drawn. NCTCOG also provided fixed entry tolls and per-mile toll rates on the various tolled segments.

El Paso Metro Region

The El Paso MPO provided zonal demographic files[5] and network data, along with travel time skims (for automobile and transit over a 24-hour period), trip production data, truck trips and external station counts for the forecast years 1997, 2005, 2015 and 2025. Mode shares for automobile trips (with occupancies of one, two and three persons), transit and walk/bike trips were provided for each of three trip purposes based on a TDM application with a 24-hour traffic assignment. The MPO also provided proportions of vehicle trips made across the day based on a 1994 household survey and 2002 external station counts. The El Paso region has 660 traffic zones and 21 external (entry/exit) stations. Currently, toll roads do not exist in El Paso and are therefore not coded in the 1997 and 2005 road networks provided by the MPO. Year 2015 was chosen as the modeling year for El Paso, since the first segment of the Northeast Parkway is expected to be operational by then. The 2015 El Paso network (4,928 lane miles) has just 36.88 tolled lane miles.

MODEL DEVELOPMENT AND CALIBRATION

Austin Model Development

Using ATS data, Kalmanje and Kockelman (2004) developed trip generation (TG) models for four trip purposes [home-based work (HBW), home-based non-work (HBNW), non-home-based work (NHBW), and non-home-based non-work trips (NHBNW)]. Home-based (HB) trip productions were computed at the household level and aggregated to the zonal level. Trip productions for non-

home-based (NHB) trips and trip attractions for all trip purposes were also aggregated. External trip productions and attractions were computed from average daily traffic counts at Austin's external stations.

Gupta (2004) calibrated joint multinomial logit models for mode and departure-time (MDT) choices, considering four modes (drive alone, shared ride, transit and walk/bike) and five time periods [late evening/early morning (after 8:15 pm and before 7:15 am), morning peak (7:15 am to 9:15 am), midday (9:15 am to 4:15 pm), evening peak (4:15 pm to 6:15 pm), and evening off-peak periods (6:15 pm to 8:15 pm)]. Her models (for each of the four trip purposes) were used in this study and are shown in Table 1. (See also Kockelman et al. 2005 and Kalmanje 2005 for more details on calibration.)

Table 1: Joint Mode and Departure Time (MDT) Choice Models (by Trip Purpose), as Calibrated for the Austin Region

Parameters	HBW	HBNW	NHBW	NHBNW
Level of Service				
Time (minutes)	-0.0548	-0.0755	-0.1808	-0.1067
Cost (¢)	-0.0098	-0.0158	-0.0460	-0.0273
Constants				
Drive Alone Morning Peak	0.3347	0.0844	1.5704	1.0032
Drive Alone Mid-noon	-0.0685	0.894	3.0372	2.6575
Drive Alone Evening Peak	0.2397	0.1872	2.1967	1.2343
Drive Alone Evening	-1.3938	-0.1143	-0.1151	0.6419
Shared Ride Late Evening/Early Morning	-2.4832	-0.6646	-2.3973	0.1802
Shared Ride Morning Peak	-2.3515	-0.5004	-0.609	0.0949
Shared Ride Mid-noon	-2.3179	-0.232	1.0072	1.5179
Shared Ride Evening Peak	-1.7653	-0.3273	-0.1476	0.9241
Shared Ride Evening	-3.5061	-0.6731	-1.6553	0.5019
Transit Late Evening/Early Morning	-5.156	-4.4493		
Transit Morning Peak	-5.3211	-3.6438		
Transit Mid-noon	-4.773	-2.7827		-6.1271
Transit Evening Peak	-5.2257	-4.0821		
Transit Evening		-5.0853		
Walk/Bike Evening/ Early Morning		-2.1292		-1.4941
Walk/Bike Morning Peak	-2.5062	-1.5052		-1.8209
Walk/Bike Mid-noon	-3.0591	-0.8871	0.9885	0.403
Walk/Bike Evening Peak	-2.7426	-2.1272	-1.0766	-1.3354
Walk/Bike Evening		-2.3116		-1.4941
Log likelihood	-6190.7479	-15998.2086	-2649.8172	-5271.8404
Log-likelihood with constants	-8742.4662	-20296.0560	-4653.9277	-7627.1100
Log-likelihood ratio index (LRI)	0.2919	0.2118	0.4306	0.3088
Number of cases	3196	7260	1877	2836

Source: Gupta 2004
Note: All parameters are significant. Drive Alone during Late Evening/Early Morning is the base case.

The TDMs include multinomial logit destination choice models for each of the four trip purposes. Destination accessibilities across all mode and departure times are captured through logsums[6] from the corresponding MDT choice models for the trip purpose, as shown in equations (1) and (2). The models used in this paper, as shown in Table 2, are Gupta's (2004) recalibrated versions of Kalmanje and Kockelman's (2004) models, and they reflect improved time and cost skim data[7], as well as improved specifications. (Kockelman et al. 2005.)

Table 2: Destination Choice Model Estimation Results

Parameters	HBW	HBNW	NHBW	NHBNW
Impedance				
Logsum of generalized costs (over modes and departure times)	0.3618	0.5714	0.1517	0.1521
Zone Size Measures				
Log(Total Employment)	0.4836	0.2284	0.4003	0.417989
Log(Population)	0.0053	0.0690	0.0409	0.039983
Log(Area)	0.0248	0.1468	0.1398	0.157174
Log-likelihood	-2322	-3743	-2148	-3265
Log-likelihood at equal shares	-3750	-7666	-4119	-6273
Likelihood ratio index	0.3797	0.5112	0.4775	0.4788
Number of observations	1,707	3,489	1,875	2,855

Source: Gupta 2004

Note: All parameters are highly statistically significant (p value = 0.01), with the exception of the HBW's Log(Area) coefficient, which is very statistically significant with a p value of 0.028.

The (systematic) utility of a destination from a particular origin is given by Equation (1).

$$(1) \quad V_{ijp} = \beta_{(ls)p} LOGSUM_{ijp} + \beta_{(emp)p} \ln(EMP_j) + \beta_{(pop)p} \ln(POP_j) + \beta_{(area)p} \ln(AREA_j)$$

where EMP_j, POP_j, $AREA_j$ are the (total) employment, population and area at the destination zone j, respectively, and $LOGSUM_{ijp}$ is the logarithm of the sum of exponential expressions for the (i, j) origin-destination pair, as shown in Equation (2). $\beta_{(ls)}$, $\beta_{(emp)}$, $\beta_{(pop)}$ and $\beta_{(area)}$ are the destination choice model coefficients (on the logsum, zonal employment, population and area terms, respectively). $LOGSUM_{ijp}$ is the expected maximum utility derived across all MDT combinations for that particular destination, and it is a measure of accessibility of that destination j from origin of interest i as follows:

$$(2) \quad LOGSUM_{ijp} = \ln\left(\sum_{m,t \in C'_{ij}} e^{\beta_{tp} Time_{ij} + \beta_{cp} Cost_{ij} + \beta_{mtp}} \right)$$

where β_{tp} is the time coefficient, β_{cp} is the cost coefficient and β_{mtp} is the MDT constant for trip purpose p, with C'_{ij} denoting the full choice set of all possible MDT combinations for trips originating in zone i and ending in zone j.

Calibration of Models for DFW and El Paso

Many regions face the challenge of not being able to calibrate their own travel demand models due to data, resources and other constraints. They look to outside experts and other regions to tap into existing models that can be suitably adapted for their needs. The problem of transferring a model from one region to another has received the attention of both practitioners and academia since the late 1970s. There are many solutions proposed, and the most effective methods require some recalibration with demographic and travel data for the new region. The transferability of trip generation models is fairly well documented, and there are many tools available. NCHRP Report 365 (Martin and McGuckin 1998) outlines these practices. For trip distribution, commonly done using gravity models, it is fairly easy to take parameters from other regions and recalibrate after a few iterations.

However, mode-choice models (and other choice models) pose some challenges. Atherton and Ben-Akiva (1976) claim that a well-calibrated mode-choice model should be transferable across regions, as long as the region's observed mode shares are matched using appropriate mode-specific constants. Tardiff (1978) strongly recommended re-estimation of alternative specific constants (ASCs) when discrete choice models are transferred across regions, because omitted model variables can greatly affect the values and variability of the ASCs. Further, Atherton and Ben-Akiva (1976) found that the best results were achieved using Bayesian estimation of the ASCs, starting with prior model parameters and then updating the estimates using new data.

Fortunately, it is possible to adapt mode choice models from other regions by systematically modifying parameters without recalibration (DFT 2003). The process involves a few iterations before producing reliable results. Ortuzar and Willumsen (1990) suggest altering the model constants (c) and scale parameter (λ) first before changing the relative values of the parameters (β).

(3) $\quad V = c + \lambda \beta' X$

where V is the systematic choice utility, c is the ASC, λ is the scale parameter, β is a vector of slope parameters and X is a vector of explanatory variables (such as time and cost).

The slope parameters are not altered at any stage, thereby implying that travelers' relative preferences for destination attributes, travel cost and time are constant across the three regions. Only the ASCs in the MDT models, which reflect the region's observed shares of mode and departure time choices, were modified. ASC values were calibrated to meet observed MDT shares by using average time and cost skims weighted by the trip estimates between corresponding traffic zones. Atherton and Ben-Akiva (1976) studied this very procedure, among other techniques, and found it to lead to reasonable results. Since the technique is relatively easy to adopt and does not require recalibration, this method was used to adapt the constants in Austin's MDT choice models to the DFW and El Paso regions.

Austin's trip generation models were not transferred. Estimates of trip productions for DFW and El Paso were obtained from their respective MPOs. The destination choice models also were not altered, since they do not possess ASCs. Changing their slope parameters would affect marginal rates of substitution, which is not the objective of this study.

Four modes and five departure-time periods were selected based on NCTCOG household survey data, El Paso mode shares (from El Paso MPO's TDM results) and time of day traffic distributions provided by the El Paso MPO. Twenty MDT combinations were developed and corresponding mode and departure time shares were computed using available data. Since data was available only for NHB trip purposes, the same shares were used for both NHBW and NHBNW trip purposes. Next, the MDT model's ASCs for DFW and El Paso were computed by equating observed and predicted MDT shares using slope parameters from the Austin MDT choice models. Trip-averaged travel time and cost values were assumed while solving for these ASCs. Trip averaging was achieved using NCTCOG and El Paso MPO OD data and travel time and cost values between all OD pairs,

using the traffic-loaded network. There is a unique set of ASCs that make the predicted shares equal the observed shares for each MDT choice – as long as the scale parameter in Equation (3) is unchanged. This is possible since the sum of all predicted probabilities equals one, and there is no ASC corresponding to the base case alternative. Solutions were obtained where the scale parameter also was changed. However, due to the lack of better data, there was no way to select any of these solutions over the one where the scale parameter was unaltered. For more details on development of the joint MDT choice models for DFW and El Paso, readers may refer to Kalmanje (2005) or Kockelman et al. (2005).

METHODOLOGY FOR CALCULATION OF WELFARE IMPACTS

This section describes the methodology used to calculate welfare impacts across travelers in each region. In this study, differences in logsums of the TDM's systematic utilities (normalized by the marginal utility of money, to ensure dollar units) were used to evaluate welfare changes. Ben-Akiva and Lerman (1985) and Small and Rosen (1981) refer to these as differences in consumer surplus or measures of compensating variation (CV). A CV measure computed at the destination choice level provides a useful and rather comprehensive measure of impacts across all destinations, modes and departure time choices. Transit service levels are also recognized in these expressions, and bus and DFW rapid transit times were assumed to fall along with automobile times.

Equation (4) gives the CV expression as a monetized *difference* in the expected maximum utilities before and after the toll roads are added. It is computed for every origin zone (assumed to be the traveler's neighborhood of residence), with $V_{i,j,p}$ denoting the utility of a trip-maker located in zone i and considering all potential destinations j for a trip of purpose p, with C denoting the full choice set of all possible destinations (as in Equation (1)):

$$(4) \quad CV_{ip} = \frac{1}{\alpha_p}\left(E_t(Max_j(V_{ijp})) - E_n(Max_j(V_{ijp})) \right)$$

where

$$(5) \quad E(Max_j(V_{ijp})) = \ln\left(\sum_{j \in C} e^{V_{ijp}} \right)$$

Here, t and n denote the scenarios with and without toll roads, and α_p is the destination choice model's marginal utility of money for trip purpose p. It can be shown that $\alpha_p = \beta_{(ls)p}\beta_{cp}$, by taking the derivative of Equation (1)'s V_{ijp} with respect to *Cost*.

CV was not computed in the above fashion [Equation (4)] for HBW trips, since work locations were held constant (for a more appropriate, short-term comparison of traffic impacts and a more appropriate, and conservative estimate of welfare impacts). Instead, CV was computed for HBW trips using the average monetized difference in logsums at the joint mode-departure time choice level, holding the work locations constant, as shown in Equation (6):

$$(6) \quad CV_i = \frac{1}{\beta_c} \sum_{j \in C} P(j \mid i) * \left(E_t(Max_{mt}(V_{mt|ij})) - E_n(Max_{mt}(V_{mt|ij})) \right)$$

where

$$(7) \quad E(Max_{mt}(V_{mt|ij})) = \ln\left(\sum_{m,t \in C'_{ij}} e^{\beta_t Time_{ij} + \beta_c Cost_{ij} + \beta_{mt}} \right)$$

P(j|i) is the probability of choosing work location *j* for a given home location *i* in the base scenario without toll roads, and β_c is the cost coefficient for HBW trips as shown in Equation (2). Equation (7) defines the maximum expected utility of mode (*m*) and departure time (*t*) choices, with C'_{ij} denoting the full choice set of all possible MDT combinations for HBW trips originating in zone *i* and ending in zone *j*.

MODEL APPLICATION TO AUSTIN, DFW AND EL PASO REGIONS

This section discusses the applications of TDM for the Austin, DFW and El Paso regions. Feedback equilibrium using the method of successive averages (MSA) and some issues with achieving feedback equilibrium are discussed.

Austin Model Application

The 2007 demographic inputs in Austin's trip generation models were computed by Gupta et al. (2005) from applying the Austin TDMs in conjunction with DRAM-EMPAL land use models (Krishnamurthy and Kockelman 2003) in a five-year feedback loop, starting in the year 1997. The Austin TDM application process is described in detail by Kalmanje and Kockelman (2004). Finally, the traffic assignment module of TransCAD (Caliper Corporation 2002) was used to arrive at a User Equilibrium (UE) assignment of traffic to the network for each of the five different time periods (AM and PM peaks, midday, evening and overnight/early morning periods). A generalized cost function [Equation (8)] based on the Bureau of Public Roads' (BPR) volume-delay equation (BPR 1964) was used in traffic assignment.

$$(8) \quad c_i(x_i) = k_i + \delta L_i + \varphi t_i \left[1 + \alpha_i \left(\frac{x_i}{C_i} \right)^{\beta_i} \right]$$

where $c_i(x_i)$ is the generalized monetary cost of using link *i* when traffic demand equals x_i, k_i is the fixed (toll) cost for link *i*, δ is the vehicle operating cost per mile (assumed to be 30¢/mile [Edmunds 2004 and Strayhorn 1999]), L_i is length of link *i*, φ denotes VOTT (assumed to be \$8/hour), C_i is the capacity of link *i*, and α_i and β_i are link parameters (BPR (1964) values of 0.15 and 4 used when values not provided by CAMPO). Since the VOTTs estimated from the mode-time of day choice models were very low (ranging from \$2.35 to \$3.36 per hour), a higher value was assumed for traffic assignment. [See Kalmanje and Kockelman (2004) and Gupta et al. (2005).]

The method of successive averages (MSA) was used to achieve demand system and network equilibrium in model applications.[8] (See, e.g., Gupta 2004 and Gupta et al. 2005.) This resulted in the use of 15 feedbacks for Austin. Transit service level changes were recognized by adjusting transit travel times after every feedback, based on the shift in the corresponding automobile travel times (i.e., bus times were assumed to decline or rise along with auto times).

DFW and El Paso Model Application

The trip productions provided by NCTCOG and the El Paso MPO were used for the four trip purposes.[9] While NCTCOG provided peak and off-peak travel times and distances for auto and transit, El Paso's MPO could provide only 24-hour values for auto and transit modes. These skims were used to initialize the simulations across five times of day and four modes. As discussed for

Austin, travel costs by automobile were generated from trip distances using a 30¢/mile conversion. The time and cost skims were used to apply the destination choice models using logsums from the DFW and El Paso MDT choice models, respectively. The other inputs to the destination choice models (like employment, population and zonal area) were all provided by the NCTCOG and El Paso MPO. Austin's return trip rates were used to convert trip production-attraction matrices to OD trip matrices, and Austin's vehicle occupancy rates were applied to obtain vehicle trip matrices for traffic assignment.

Morning and evening peak, and 24-hour off-peak capacities were provided by NCTCOG for the DFW network. The off-peak capacities were proportionally divided among the three off-peak periods in this study (T0, T2 and T4). User Equilibrium (UE) traffic assignment recognizing the presence of HOV lanes was used. While drive alone and truck trips were excluded from the HOV lanes, shared ride trips are allowed. A $10/hr VOTT was used for DFW during traffic assignment, based on NCTCOG values. Eleven feedbacks using the MSA procedure were used to achieve user equilibrium for the DFW application.

The El Paso MPO provided 24-hour capacities for the El Paso road network. This was converted into two hour peak (for peak periods: T1 and T3) and off-peak capacities (for three off-peak periods: T0, T2, T4). Twenty percent of 24-hour capacities was assumed for the peak and 25% of the 24-hour capacities for the off-peak. This study assumed a 10¢/mile toll on the toll links in El Paso. Actual planning data was not available to determine the toll values. Single class UE assignment with the generalized cost function was used just like in the Austin case. The traffic assignment procedure used was UE generalized cost assignment. An $8/hr VOTT was used for traffic assignment, just like in the Austin case. Fifteen feedbacks using the MSA procedure were used to achieve convergence in the El Paso application.

The following sections compare the results obtained for the three study areas before and after toll roads were added to the respective networks. Traffic, revenue generation, and welfare impacts are discussed in detail in the following sections.

TRAFFIC IMPACTS OF TOLL ROADS

The traffic impacts of toll roads are expected to be a function of distance to the toll roads, as well as regional centers of population and employment. To achieve this objective, two *neighborhoods* or *bands* were constructed around the toll road corridors, at distances of five miles and one mile. Figure 1 shows these neighborhoods for each of the three Texas regions.

Table 3 shows the variations in vehicle miles traveled (VMT), vehicle hours traveled (VHT), VMT-weighted mean speeds and VMT-weighted volume-to-capacity ratios (v/c ratios) both *before* and *after* the addition of the new toll roads. In order to emphasize traffic impacts on the current (before) network links, all results/all neighborhoods in Table 3 exclude the new toll roads.

From Table 3, one sees that the Austin and DFW regions exhibit fairly uniform trends in traffic impacts of the new toll roads. Speeds increase (and v/c ratios fall) as one nears the tolled roads. Regional VMT and VHT values (not including the new toll roads) are predicted to fall. Interestingly, these reductions are greatest in the Austin region, on the roads nearest the toll roads. In contrast, roads nearest the DFW toll road additions are predicted to experience a substantial increase in their current VMT levels, suggesting that route shifts are substantial and will load connectors. These connectors are capacity-constrained and may experience speed reductions, even though VMT and VHT are falling overall (when use of the new toll roads is not included in the calculations). The ELP network was hardly affected at all, with all VMT, speed, VHT and v/c shifts estimated to be less than 1%.

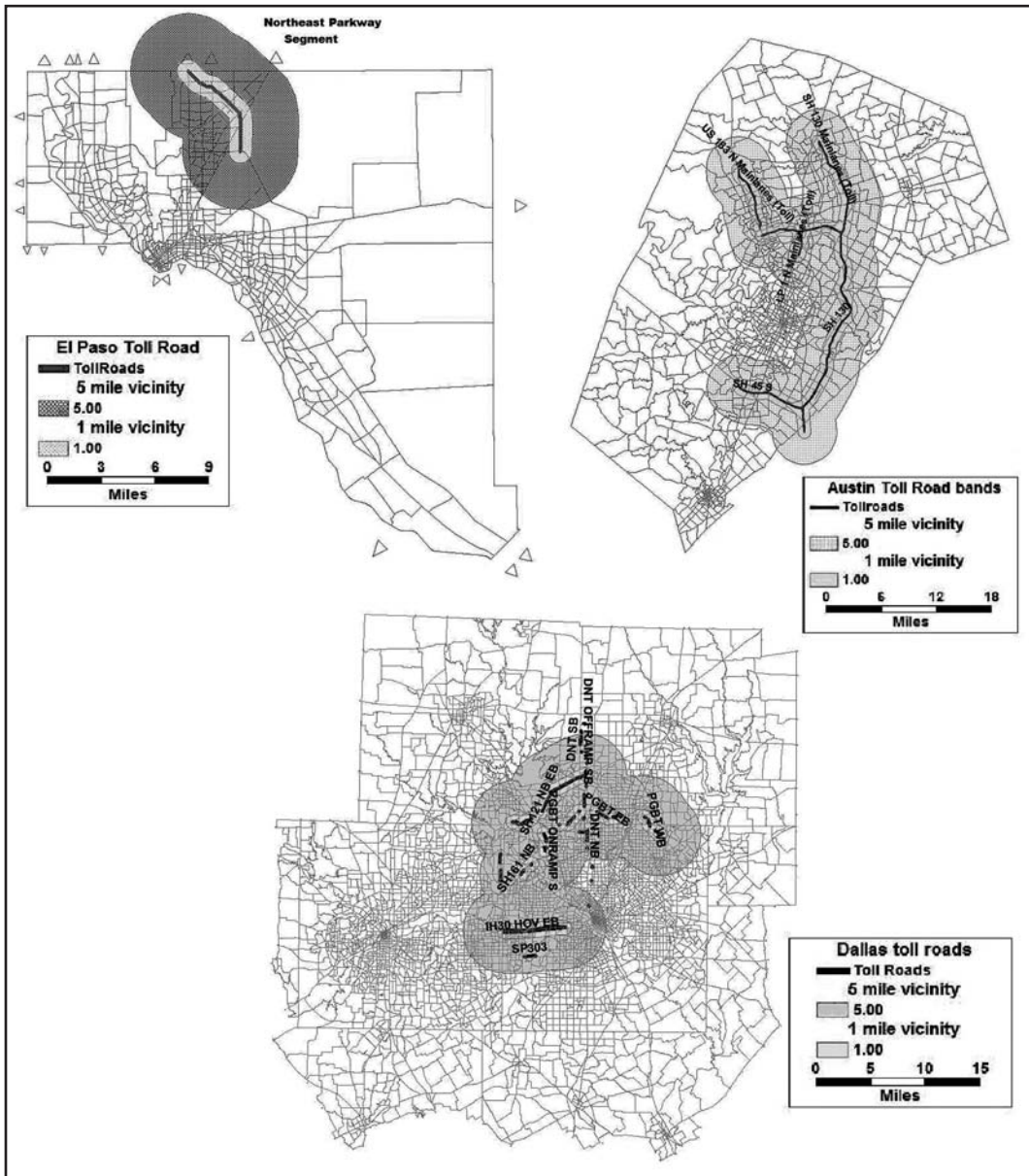**Figure 1: Five-mile and One-mile Neighborhoods for the El Paso, Austin, and DFW Toll Roads**

Table 3: Percentage Variation in VMT and VHT on Existing Roads for Different Neighborhoods

Region	VMT/VHT	Percentage Variation		
		All roads	Five-mile Vicinity	One-mile Vicinity
Austin	v/c (VMT weighted)	-0.64%	-2.04%	-6.13%
	Average speed (VMT weighted)	-0.05%	0.05%	0.49%
	Daily VMT	-0.52%	-1.02%	-0.55%
	Daily VHT	-0.53%	-1.10%	-1.20%
DFW	v/c (VMT weighted)	-1.27%	-1.56%	-1.83%
	Average speed (VMT weighted)	0.82%	1.28%	8.93%
	Daily VMT	-0.82%	-1.13%	11.47%
	Daily VHT	-1.69%	-2.41%	0.84%
El Paso	v/c (VMT weighted)	0.41%	0.16%	-0.21%
	Average speed (VMT weighted)	-0.09%	-0.03%	-0.04%
	Daily VMT	-0.01%	-0.08%	-0.29%
	Daily VHT	0.22%	-0.05%	-0.26%

As one would expect, VMT-weighted average toll road speeds (62 mph, 53 mph and 42 mph for DFW, Austin and El Paso toll roads) are substantially greater than average speeds on nearby roadways, since these toll roads are designed to freeway standards and are relatively uncongested. However, there are many differences in the nature of traffic impacts across the three regions. The congestion reducing impacts in El Paso are quite localized to the one-mile vicinity of the toll road and to off-peak periods. In contrast, new toll roads in Austin and DFW are predicted to have fairly uniform effects across their regions and across time periods. Differences are expected, of course. El Paso's is a bypass to some extent, and Austin's SH130 is a bypass. Also, most of Austin's toll roads are connected to each other. In contrast, DFW's are largely central, without direct connections to one another.

Of course, added roadways can attract more trips, offering benefits to local businesses due to easier access. Total predicted trip attractions within the one-mile and five-mile neighborhoods were computed before and after the addition of toll roads; the TDMs predicted very slight increases in attracted trips. Only minor variations were observed by trip purpose. Increases are predicted to exceed 1% only in the case of El Paso's one-mile neighborhood. This suggests that, in the short term, toll roads may not have a significant impact on trip attractions, and the effects may be greatest for smaller regions like El Paso. In the longer term, of course, enhanced access may spur relocations and new land development alongside the toll roads, resulting in greater trip attractions.

REVENUE GENERATION IMPACTS OF TOLL ROADS

As expected, toll revenues are largest during peak periods when volumes are greatest. New toll road revenues are estimated to be just $94/day in El Paso, $13,221/day in Austin and a striking $503,984/day in DFW. In DFW, *net* revenues are somewhat lower ($407,809 per day), due to diversion of some traffic from existing toll roads. Nevertheless, the added lanes are expected to be very valuable. Clearly, these revenue results suggest some potentially serious issues for cost recovery in El Paso and even Austin. The revenues translate to $2.54, $27 and $3,344 per day per lane mile in El Paso, Austin and DFW, respectively, or $928, $9,878 and $1.2 million per lane-mile per year. Assuming a construction cost of $2 million per lane-mile, only the DFW toll roads are predicted to be profitable by these models. In the longer term, growing populations, job relocations and rising VMT may result in revenue increases. In general, these results seem to suggest that the location of DFW's new tollways (centrally, rather than peripherally), the existence of other tolled routes in DFW (some

potentially serving as substitutes) and general congestion make for a potentially very profitable tolling scenario in the DFW region. Austin's planned roads extend to the periphery and do not serve highly developed locations. El Paso's planned tollway is on the edge of the region and is quite short. Rather crucially, El Paso's tollway ties into the low-density regional periphery and is therefore only able to attract and affect a very small proportion of trips. If a larger modeling region/zone system were used, and an IH10 bypass of downtown ELP were to be added as planned to tie into this toll road (from the north and western side of the region), traffic and revenue predictions could be much higher. In essence, El Paso's current modeling region is probably very inadequate for appraisal of this new road's evaluation.

WELFARE IMPACTS OF TOLL ROADS

Compensating variations were computed by trip purpose for all three regions using Equations (4) and (6), as described earlier. The geographical distribution of CVs for HBW and HBNW trips are shown in Figures 2, 3 and 4 for the El Paso, Austin and DFW regions, respectively. In all cases, zones closest to the new toll roads are predicted to gain more than those farther away. Benefits are estimated for the great majority of the region's "average" trips (by origin), but these are slight – a maximum of 12¢/trip in El Paso and Austin, and 4¢/trip in DFW.

Figure 2: Net Traveler Benefits Following Toll Road Addition in El Paso for HBW and HBNW Trip Purposes
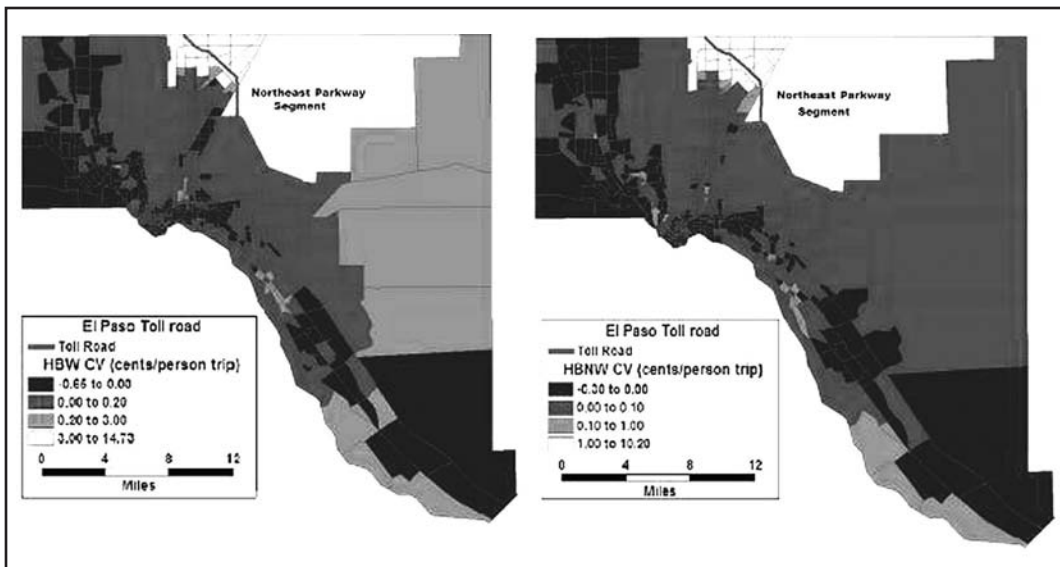
Austin trips originating near the intersections or very ends of the toll roads are predicted to benefit most. Simpler relationships are observed in El Paso and DFW, where only a single toll road is being added (El Paso) or the additions are not connected (DFW). In effect, the El Paso and DFW toll roads operate independently, while Austin's form much more of a regional network, producing more complex impact patterns. Interestingly, revenue gains are highest in DFW (by a wide margin), though welfare changes appear less significant in that region.

Any predicted welfare losses in all three regions are very low (typically less than 1¢/trip), and these generally are visible at the regions' edges, away from the toll roads. They are felt to be biased low, stemming from a divergence in assignment and mode choice value-of-time assumptions rather than from any actual travel disbenefits. Edge effects can also arise, to some extent, from the artificial boundary that constrains travel choices in those zones, permitting less flexible patterns of response (e.g., choosing destinations outside the defined region).

Figure 3: Net Traveler Benefits Following Toll Road Addition in Austin for HBW and HBNW Trip Purposes


In theory, road additions – even if they are tolled additions – should facilitate trip-making and thus enhance traveler welfare, as measured in this work. These benefits are generally expected throughout a region, though certain responses (such as longer trip-making) may negatively impact some links (such as those close to the DFW toll road additions) and thus some trip-making. Therefore, any welfare losses predicted by these models are not immediately intuitive. The use of a higher VOTT during traffic assignment, as compared to the choice models, is felt to be the reason for this discrepancy. VOTTs for route choice/network assignment were assumed to range from $8 to $10/vehicle/hour, while those in choice of mode (and thus destination) were assumed to vary between $2.35 and $3.36/person/hour. The first assumption resulted in relatively more traffic assignment to faster, tolled links than is perfectly consistent with time-of-day and destination preferences. So there is reason to believe that these models are consistently underestimating welfare benefits. Moreover, the focus on an "average" traveler and single VOTT for all is limiting: In reality, these regions have a wide range of traveler and trip types, and multi-class traffic assignment and welfare analyses should prove helpful.

CONCLUSIONS

This work examined the nature of travel responses to the addition of toll roads in three Texas networks. Models were calibrated for Austin and adapted to the DFW and El Paso regions. These regions differ in size, travel demand and network configuration. As expected, there are variations in their predicted responses to toll roads, but also some general patterns.

Figure 4: Net Traveler Benefits Following Toll Road Addition in DFW for HBW and HBNW Trip Purposes
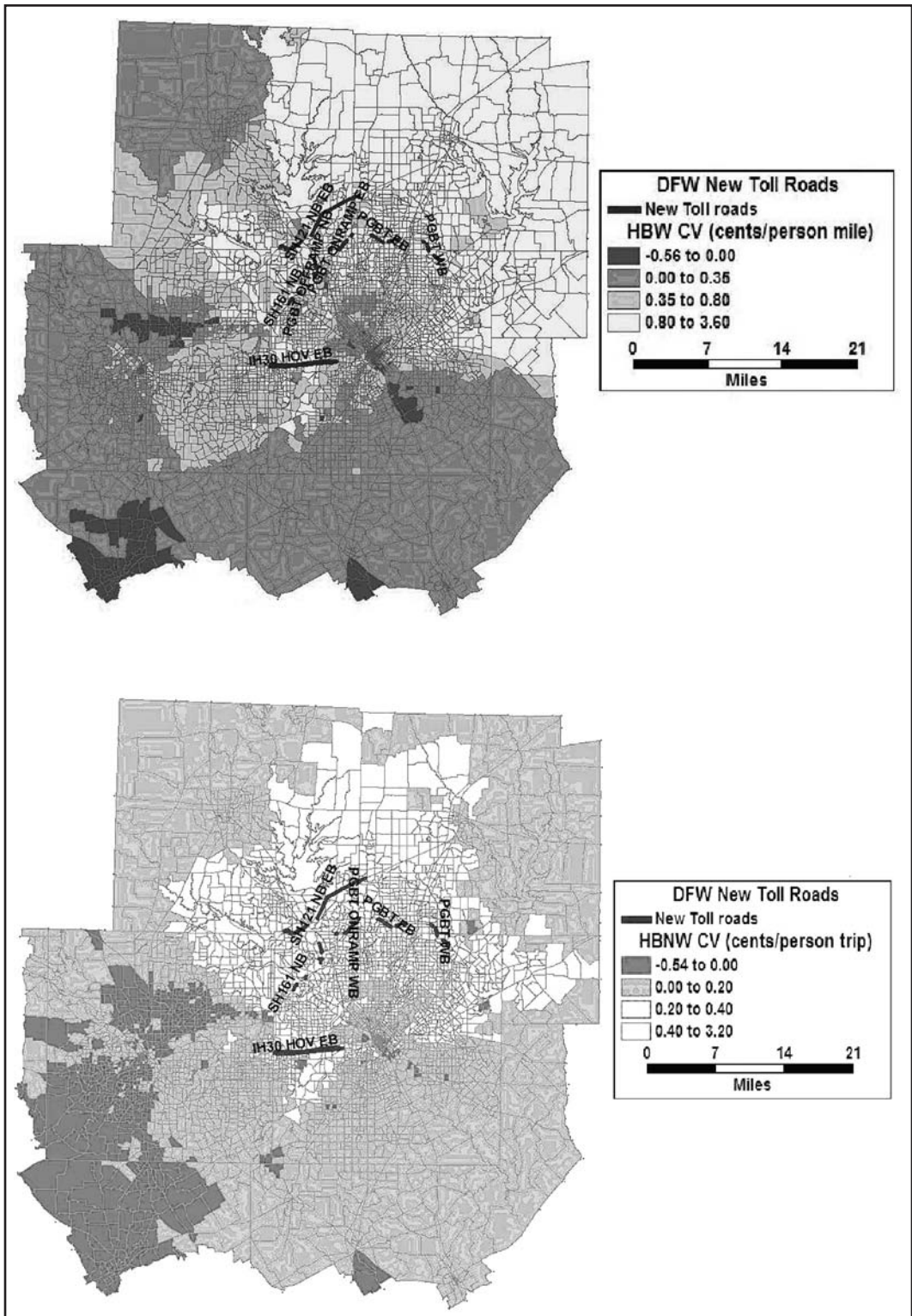
Results for El Paso indicate that the gains from congestion reduction are concentrated within a one-mile neighborhood of the toll road, with negligible impacts elsewhere. Traveler benefits are estimated to be largest for zones lying northeast of the toll road, which bypasses the region's downtown. In the Austin case, several new toll roads facilitate access to the region's core, causing mean travel speeds to improve rather uniformly, indicating overall system improvement. The resulting distribution of welfare benefits are complex, in contrast to the relatively simple relationships exhibited in El Paso and DFW, where traveler welfare predictions fall rather uniformly with distance from the new toll roads. In Austin, the greatest benefits arise near toll road intersections and ends of the system.

Near-term revenues (per lane-mile) are predicted to be substantial in DFW ($3,344 per lane-mile per day) but low elsewhere. Toll road use in El Paso, based on 2,015 trip production and attraction values, is predicted to be very minor. But this result may be largely due to the definition of regional boundaries (the new road ends at the boundary, substantially limiting adaptation of interregional and local traffic patterns). Of course, all three regions are growing, and their land uses will evolve over time to make better use of the access opportunities offered by capacity additions, tolled or untolled. Forecasts of future populations and land use model predictions would enhance these travel demand model applications. Moreover, calibration of the DFW and El Paso travel behaviors based on local travel survey data would add realism and should improve prediction accuracy. Low VOTT estimates arising in the mode-choice models were at odds with those used for network assignment (which were felt to be more reasonable), and this reduced the welfare estimate. Ideally, a greater consistency would exist there. Furthermore, multi-class assignment, recognizing a variety of traveler types, and behavioral models responsive to a variety of demographic features are a paradigm that all modelers aspire to. This is a difficult class of problem and research is underway around the world. In the meantime, these models and evaluations of their predictions offer insight into regional responses to tolled capacity additions. The ability to rigorously examine traffic and traveler welfare impacts by neighborhoods is quite valuable and should prove useful to policy makers needing to objectively select toll road projects in the face of often passionate public scrutiny.

Acknowledgements

Endnotes

1. Basic jobs often include jobs associated with agriculture, forestry, fishing, mining, construction, manufacturing, services of transportation, communications, electric, gas, sanitation and wholesale trade. Retail jobs include retail trade occupations, and Service jobs include finance, insurance, real estate, services and public administration jobs.

2. Zonal-based estimates of households, population and employment (by basic, service and retail sectors) for the years 1999 and 2007 were available, along with land area and median household incomes.

3. External (entry/exit) stations refer to entry and/or exit points on the boundary of the model area, which control the inflow and outflow of traffic to/from the model area.

4. In the year 2007, the DFW network had 145 tolled links (183.8 lane miles), of which 97 links (150.7 lane miles) belong to post-November 1999 toll roads, namely, PGBT, SH121, SH161 and IH30 HOV lanes. The remaining tolled links correspond to pre-1999, existing toll roads (namely, DNT, MCLB and AAT) and their post-1999 extensions.

5. The demographic files contain information on zonal population, employment (basic, retail and service sectors), number of households and zone type (urban, suburban and rural).

6. Logsum refers to the logarithm of the sum of exponential expressions involving the systematic utility components of all alternatives in logit choice models (see, e.g., Kalmanje and Kockelman [2004]).

7. Time and cost skims are the travel time and travel cost values for shortest-paths between all zone pairs, as "skimmed" off the network under equilibrium traffic flows.

8. System equilibration involves assigning traffic to routes to serve demand, then averaging these initial flows with those resulting from the new travel time estimates, successively, until flow changes across iterations are minimal (meeting a 1% relative gap convergence criterion in TransCAD).

9. Since trip production data was available only for NHB trips as a whole (and not separately for work and non-work trips), the NHB trip productions were equally split to obtain NHBW and NHBNW trip productions.

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