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Application of Credit-Based Congestion Pricing in Texas: Operational Considerations and Impacts

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Products

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Executive Summary

Credit-based congestion pricing (CBCP) is a novel strategy that seeks to overcome the negative equity impacts of congestion pricing (CP) by allocating monthly budgets to eligible travelers to spend on congestion tolls. Previous CBCP studies have surveyed public opinion and examined the traffic and travel welfare impacts of an Austin, Texas, application. This work develops the policy further, examining expert opinions, predicting traffic impacts, estimating air-quality changes, and predicting system costs.

We surveyed transport economists, toll technology experts, administrators, policy makers, and commercial interests for feedback on credit distribution, revenue uses, technology, costs, and system-wide impacts. Various issues involving the different possible uses of CP toll revenues were discussed.

A synthesis of some of the experiences from recent congestion pricing demonstration projects and a formal procedure for evaluating the appropriateness of various technologies were developed. One benefit of the synthesis was the development of more precise measures of performance to evaluate the potential technologies. Subsequently, we conducted the evaluation using a state-of-the-art evaluation algorithm, ELECTRE IV, which overcomes many drawbacks of other evaluation approaches. The usefulness of the approach was demonstrated on a subset of tolling technology alternatives, some of which were tested in Europe's PRoGReSS demonstration projects. In the near term, radio-frequency identification (RFID) is found to be the optimal choice; in the longer term, digital short-range communication (DSRC) technology should become a wise choice, thanks to increasing affordability.

In addition to these syntheses of existing experience and surveys of opinions, travel demand models were calibrated and applied. Joint destination-mode choice models were estimated for the Dallas–Fort Worth (DFW) region. Status quo and two marginal cost pricing (MCP) scenarios were simulated for the short term and long term, with full feedback, using the method of successive averages for equilibration. As expected under such a policy, total regional vehicle miles traveled were predicted to fall and speeds increase, though significant mode shifts are not predicted. Air quality improvements are also hoped to be a valuable benefit of CBCP, as predicted by mobile source emissions, estimated using MOBILE6. Total travel benefits were quantified as the welfare changed between the MCP scenarios and the status quo. On average, most of the DFW population (about 95 percent of the "budget-eligible" travelers) is expected to gain from the CBCP policy.

The DFW welfare analysis did not predict significant benefits to come from pricing all roads, when compared to the case when only freeways are priced. Reasonably detailed estimates of policy implementation costs for the DFW region were generated, along with estimates of MCP toll revenues. These resulted in possible CBCP traveler budgets, which suggest that implementation costs may consume 42 percent of revenues, leaving the remainder for revenue distribution. In addition to the standard methods of network equilibration for the DFW region, a simulation-based dynamic traffic assignment (DTA) software was employed to evaluate the status quo and the MCP scenarios when only freeways are priced. Due to highly intensive computational requirements for large-scale DTA applications (i.e., the DFW network), the status quo and MCP scenarios were simulated without feedback (of travel times and costs, for destination and other choices). Only route choices were permitted to vary. Given the static demand levels estimated for the region's five traffic assignment periods, smooth demand profiles were generated for every origin-destination zone pair, every six seconds in the three-hour AM peak period. During application, MCP tolls were updated every five minutes. Dynamic prices varied substantially over the analysis period, reflecting changes in congestion. When prices were imposed, some minor system benefits were observed, including delays in the onset of congestion. As computational limitations erode, future implementations should incorporate destination, departure-time and mode-choice decisions.

The two-year project generated a great deal of interesting investigations and valuable results. Based on the various application results, interviews, and synthesis of the pricing literature, this report offers detailed recommendations for actual implementation of CBCP-type policies.

1. Introduction

1.1 Introduction

Traffic congestion has plagued drivers almost since the inception of the automobile itself. Arnott and Small (1994) estimated that in U.S. cities with a population of over one million, a third of vehicular travel takes place in congested situations, where speeds are less than half the free-flow speeds. Schrank and Lomax (2003) estimated the yearly fuel and time costs of congestion in seventy-five major U.S. cities as $69.5 billion. This boils down to $520 per person annually, though of course the figure is much higher for those who are actually involved in the congestion. Building new roads or increasing capacity of existing roads to alleviate congestion is prohibitively expensive most of the time. According to the Pigou-Knight-Downs paradox, increasing capacity can allow latent demand to consume much of the travel time savings. Thus, demand management is key. Strategies include making the trips shorter and less frequent, and spreading them over different modes, routes, and time periods. This could be done by tolling congested roads, or congestion pricing (CP). This chapter first discusses the origins of CP, then reviews previous work to overcome the deficiencies of CP. Kockelman and Kalmanje's (2004) proposal for credit-based congestion pricing (CBCP) is discussed.

1.2 Congestion Pricing

The concept of road space rationing is not new and dates back to early in the 20th century (Pigou 1920; Knight 1924). Early work in CP includes that by Vickrey (1963), who observed that an effort was underway to differentiate between peak and off-peak demand in several markets (e.g., hotels, airlines, theaters, and telephone services), and something similar for transportation would be useful. Following Vickrey (1963), researchers have extensively discussed the potential of CP for congestion mitigation.

Several CP pilot projects have been implemented worldwide, for example, San Diego's highway I 15, London's central cordon toll, Singapore's system tolls, and the bridge and highway tolls of Lee County, Florida. All of these projects employ electronic toll collection (ETC) to avoid delays from queues at toll collection booths. Appendix A1 provides a summary of the impacts of pricing in these locations.

However, there are many disadvantages associated with CP. In a congested region CP has the potential to transfer a great deal of money from the traveling public to toll collecting authorities. A certain portion of such revenues is needed to cover the costs of a CP program (e.g., paying for roadside detection devices, variable message signs, toll collection, and general program administration). The rest arguably should be used to compensate (directly or indirectly) "the public" at large, who funded the road's original construction and its operation via taxes. Of course, if such persons are compensated in proportion to how much they pay or how much they drive, there is no incentive to change their travel behavior. Paying a higher amount to those who drive more (and hence pay more) or have higher vehicle ownership actually provides an incentive for people to drive more or own more vehicles, which runs counter to the objective of congestion mitigation.

Past research has explored various revenue distribution strategies. For example, Small (1992) proposed a travel allowance for all *commuters*. He recommended a fixed amount per month per employee, regardless of mode or time of travel so that CP incentives (i.e., reduced driving on congested roads) would not be undermined. Taking a different approach, Parry and Bento (2001) recommended that income taxes be reduced, to offset any CP-related labor supply restrictions. Goodwin (1989) and Small (1992) suggested combinations of revenue uses, in order to offset several CP impacts.

Under standard CP few travelers may benefit sufficiently from the resulting travel time savings to appreciate the policy. This is particularly true in the short run, due to fixed home, work, and school locations. (See, e.g., Arnott et al. 1994 and Parry and Bento 2001.) Though CP may have the potential to benefit society as a whole (i.e., be Pareto improving) if funds are distributed optimally, it can adversely affect certain user groups (e.g., low-income users and commuters with little or no work flexibility). Researchers have discussed the potential for offsetting CP's adverse effects while maintaining certain behavioral incentives. Gee and Hannemann (2002) proposed compensation of persons negatively impacted by CP in the same "dimension" as the impact (such as free weekend parking for those less able to pay weekday tolls). Dial (1999) recommended always providing a "free" route, via minimum-revenue CP. DeCorla-Souza (1995) suggested toll credits for regular drivers via FAIR (Fast and Intertwined Regular) lanes. And Viegas (2001) proposed providing a certain level of "mobility rights." Recently, Kockelman and Kalmanje (2004) proposed a policy called credit-based congestion pricing (CBCP) to address the potentially adverse effects of traditional CP.

1.3 Credit-Based Congestion Pricing

A CBCP policy, as conceived by Kockelman and Kalmanje (2004), has the potential to allay many if not all equity concerns. It explores a different approach to CP, based on traveler "credit allowances" similar to the "tradable" emission credits set up by the 1990 Clean Air Act Amendments (CAAA 1990). In Kockelman and Kalmanje's (2004) work, the term "credit" refers to a monetary cash out. Every eligible traveler (e.g., every licensed driver living in the designated "priced region") may be given a monthly budget of "credits" to spend on travel—or on anything else. Those in the driving population who exhaust their travel budget (by driving on tolled routes during congested times of day) will pay out of pocket to keep driving, while those who save their travel budget can cash this out as a direct monetary saving. Each month's travel allowance depends on the total revenue collected during that (or the previous) month. Revenue neutrality is maintained by returning all revenues, after covering administrative costs.

Kockelman and Kalmanje (2004) polled the Austin, Texas, public about such a policy and found it to compete reasonably well with transportation policy alternatives. The support for CBCP was twice as high among people who had heard about CP (50 percent) as compared to those who had not (26.5 percent). This indicates that educating people about CP's merits may have a very favorable impact on public perception. The survey asked respondents to rate various pricing policy attributes, such as ease of use, fairness, cost to users and privacy. The study weighted responses for demographics. The data was analyzed after correcting for sample biases (to reflect the population at large in Austin). About 70 percent felt user costs to be very important, 58 percent were concerned with implementation issues, 56 percent believed fairness to be an important issue, while 32 percent described privacy as being important. Kockelman and

Kalmanje (2004) also surveyed people about changes in their stated travel behavior under peak-hour distance-based tolls.[1]

In a different paper, Kalmanje and Kockelman (2004) predicted Austin area trip-based welfare impacts and land value changes for two different CBCP scenarios. CBCP was found to benefit most residents, whereas standard CP (without revenue redistribution) benefited relatively few. System-wide marginal cost pricing (MCP) decreased average peak travel times by about 1.6 percent (3.3 percent on major highways). For Austin, a CBCP policy with all roads priced according to marginal delay costs was expected to return around $.50 per traveler per day, while such pricing on major highways only was expected to return about $.20 per traveler per day. A small overall drop in residential property values was predicted when CP was imposed on all roads, while a small rise in downtown property values was estimated when imposing CP only on major highways. Property values were predicted to drop marginally in some areas. However, the predicted decreases would be even less in a CBCP scenario, since the inherent rebate would offset the diminished access effects experienced by the regions.

1.4 Conclusions

Congestion is a pervasive problem for many, if not all, urban areas. With capacity additions being very expensive and latent demand neutralizing expansions (Arnott and Small 1994), demand management may prove the most desirable solution. Vickrey (1963) suggested that peak-period travelers impose a higher cost (in the form of delay costs on fellow travelers) than off-peak travelers. The average traveler observes his/her private costs while traveling, but the social optimum can only be realized if he/she also faces the comprehensive social cost of his/her trip. This can be achieved by charging users a congestion-dependent toll. There have been many pricing projects (including CP) worldwide, as well as much research in this topic. However, CP has certain drawbacks, with equity proving a prominent issue. Researchers have suggested offsetting CP's adverse effects by several means, including commuter credits, income tax reductions, property/gas tax reductions, and FAIR lanes. Kockelman and Kalmanje's (2004) revenue-neutral CBCP has the potential to allay such equity concerns in a fundamental way.

Recognizing CBCP's potential as a viable and equitable congestion management strategy, this study explores the policy in further detail, and refines it based on opinions of transportation experts, policy makers, stakeholders, and special interest groups. Experts and stakeholders were asked a wide range of questions related to the application of CBCP on Texas highways. Chapter 2 provides a synthesis of their opinions, concerns, and suggestions. Transportation agencies may wish to invest the CP revenues in a variety of ways (e.g., capacity additions and maintenance, tax-reduction, development of non-auto alternatives, and crediting travelers). Chapter 3 discusses such uses of CP revenue.

The first step in predicting CP's impacts involves traveler behavior modeling. Joint destination-mode (DM) choice models were estimated for different trip purposes from the DFW household

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[1] This study considered conducting a similar survey of Dallas–Fort Worth (DFW) residents. However, the survey was not implemented due to agency concern that the DFW public might confuse the CBCP policy with other toll road proposals for the region. The survey may be conducted in the future and is given in Appendix A2.

and transit on-board survey datasets. Chapter 4 discusses the model estimation procedures and the resulting parameter estimates. The joint DM choice models were applied region-wide to simulate the status quo[2] along with two MCP scenarios (MCP-on-freeways and MCP-on-all-roads) for the DFW region for 1999. Full model feedback of travel times and costs was implemented, and the method of successive averages (MSA) was used for route, destination, and mode choice equilibration for each of five daily time periods. Chapter 5 compares the traffic impacts of the two MCP scenarios to the status quo. The welfare changes under CBCP are also presented. Based on estimates of link flows and speeds emissions of different pollutants and particulate matter were estimated as a function of speed using MOBILE 6. Chapter 6 discusses the emissions estimates and the key results. Chapter 7 summarizes expert and stakeholder feedback, to produce a series of policy recommendations. It also includes a summary of implementation costs and CP revenues. Chapter 8 synthesizes the experiences from recent congestion pricing projects and provides a formal procedure for evaluating the appropriateness of various technologies. Chapter 9 compares the traffic impacts of the MCP scenario (when only freeways are priced) to the status quo, using dynamic traffic assignment. A comparison of the static and dynamic traffic assignment results is also provided. Chapter 10 concludes the report with a summary of all chapter methods and results. The appendices contain a summary of CP case studies, discussion on ETC technologies, CBCP survey for DFW public, responses from experts and stakeholders (and their contacts), GAUSS codes of joint DM choice model estimation, and other relevant information as appropriate.

[2] Status quo refers to the current situation, i.e., without MCP on any road.

2. Summary of Stakeholder and Expert Perspectives

2.1 Introduction

An extensive survey of stakeholders and experts related to the application of credit-based congestion pricing (CBCP) was undertaken in February 2004. The survey sample included 140 academicians and practitioners in the fields of transport economics, toll technology, administration, and policy. A distinct survey was created for each field to target respondents' expertise and views on a range of issues related to CBCP. Following an initial greeting and introduction, the CBCP Policy was described, and then a variety of relevant questions asked. The policy description provided in the questionnaire is given in Appendix B1. The questions differed by respondent type. The questionnaires for transport economists, toll technology experts, administrators and policy makers, and commercial users are given in Appendices B2, B3, B4, and B5, respectively. Appendix B10 gives the contact information for all respondents.

Fifty individuals responded to the surveys after multiple follow-ups via e-mail and telephone. The following sections discuss their responses.

2.2 Synthesis of Expert Perspectives

This synthesis of respondent perspectives first discusses the CBCP equity issues raised by the respondents, their initial impressions of the policy, and their suggestions to make it more effective. It then describes predicted economic impacts and land use changes, commercial user reactions, and anticipated business impacts. Respondent concerns over CBCP, opinions on revenue use and their expectations of public reaction to the policy are presented. Finally, experts' recommendations for technology, dynamic pricing, and data requirements are compiled. All e-mailed responses are quoted verbatim in the following appendices: transport economists: Appendix B6; toll technology experts: Appendix B7; administrators and policy makers: Appendix B8; and commercial users: Appendix B9. The expressed opinions are personal and do not reflect the views of any organization.

2.2.1 Budget Allocation and Equity Issues

Transport economists expressed concern over the many possible persons that would receive a travel budget, whether or not they used the priced corridors. Some of the economists expressed concern that it appeared that everyone with a driver's license (e.g., high school students) would receive a travel budget. Several felt that differential budget allocations would make CBCP more of a welfare program and expressed that transportation policies are not efficient for income redistribution.

There was feedback on a variety issues relating to the policy's equity. The transport economists considered departure time flexibility and value of time to be important factors in determining the policy's benefits for any specific individual. A transportation engineering professor felt that office workers and others required to travel during peak periods would be most negatively affected, while those with less travel time constraints or traveling at the off-peak would benefit (e.g., non-workers and industrial shift employees). Policy makers and commercial users indicated that people living in certain zones could be disadvantaged since alternatives to peak-period driving are not the same in all zones (e.g., public transit does not serve all neighborhoods).

Transport economists suggested that low-income people traveling longer distances to work could be adversely affected since they tend to choose low-cost housing away from activity centers. So allocating an equal travel budget to everyone might leave persons of low income less well off than before the policy was implemented. A similar opinion was expressed by some policy makers who mentioned that current inequities (e.g., access to facilities and jobs) may be magnified under CBCP. However, some respondents opposed any budget allocation that would be based on income. They felt that verifying income would be administratively burdensome and would create an opportunity for significant fraud. All four respondent types were of the opinion that budget allocation per adult resident would benefit the presently disadvantaged while allocation per-registered-vehicle would reward vehicle ownership (and thus benefit the well-off).

2.2.2 Economic Impacts and Land Use Changes

A majority of the respondents thought that CBCP would stimulate the economy. However, some did not expect any noticeable changes, and a couple suggested that CBCP might actually dampen the economy. If the strategy is accepted by the public and resolves congestion problems, then it should benefit the local economy. However, this could potentially result in greater population growth, thus increasing travel demands and exacerbating congestion. If capacity expansion is not required, the government might invest the capital elsewhere, which also could be good for the economy. A transportation engineering professor, however, expected local investment to fall if the city became viewed as "quasi-communist" by investors and others.

Almost all respondents (among transport economists) predicted more compact land development if CBCP were to be implemented, thus decreasing sprawl. They did expect location and travel demand shifts though; people would have an incentive to move closer to jobs, carpool, and travel off-peak, thus decreasing peak travel (e.g., see Kalmanje and Kockelman 2004). Respondents expected an increase in the demand for transit-oriented development and a decrease in the long-run demand for additional highway capacity. Housing was predicted to become more centralized and employment less centralized. Respondents suggested that businesses based in the CBD would become less attractive compared to those in suburban sites, since accessing the CBD would become costlier. (Of course, such "cost" depends on the traveler's value of time, so CBD access actually should become less expensive for those who are willing to pay to avoid delays.) Any further land use changes would depend on the way the policy is implemented (e.g., budget allocation and pricing policies).

2.2.3 Commercial Users' Perspectives and Predicted Business Impacts

While some commercial users (mainly local businesses) saw a benefit to less congestion, most reported having already shaped their business practices to cope with high levels of congestion. In fact, they appeared uninterested in the benefits that their region's transportation and distribution systems might see, and instead considered primarily any *personal* disadvantages (i.e., increased costs of solo commuting). This response may reflect the growing reliance of businesses on outside companies, such as shippers and couriers, for transportation and distribution. As outsourcing of transportation and distribution becomes more ingrained in business models, incentives for timely delivery no longer reside so much in these commercial entities but in their shippers and couriers. This trend may undercut incentives that reduced congestion levels might bring to many commercial users.

Those who depend heavily on timely product and service deliveries indicated a clear willingness to pay a premium to guarantee such deliveries. Office-based employers were willing to support some congestion mitigation policies, as part of an effort to reduce regional pollution. There was very little interest in subsidizing employee-related CBCP costs. A common perspective seemed to be that employees must plan to get to work on time, irrespective of where they live.[3] Most stressed that they offer, or most likely would offer, a "flex-time" workday option, where employees have a range of hours in which they may work, as opposed to a standard workday. If customer levels increased during a certain time of day due to CBCP, several of the service-centered businesses said that they would change staffing hours to accommodate the flux in customer volumes. One indicated that telecommuting could become more necessary, and its effect on congestion may be pronounced.

2.2.4 Concerns about CBCP

Respondents were asked to rank CBCP issues that most concerned them.[4] The biggest concern for the transport economists lay in the proposed uniform allocation of travel budgets to all possible roadway users. Next was the policy's administrative cost burden. Most transport economists did not consider privacy and technological feasibility to be major issues. However, a couple noted these to be their principal concerns. Others were more concerned about political feasibility, traffic impacts, and land use impacts. Some of the economists also expressed concern about traffic spillovers onto non-priced streets. The policy makers brought up the issue of the agency that would be needed to administer such a system. Since CBCP could apply region-wide, administration then would have to extend beyond the municipal level. One policy-maker suggested that Texas's Regional Mobility Authorities (RMAs) created under HB3588 would be an option. But revenue handling could be complicated. "Rat-running" onto some local streets (to avoid tolls) may harm some locations, which may demand some of the collected revenues in order to improve their own infrastructure. Smaller communities, beyond the region's fringe, may lobby for admission to the policy region if their residents were not given travel budgets for use of the region's roadways. Such concerns may make revenue-neutrality a difficult goal.

2.2.5 Alternative Revenue Uses

Though Kockelman and Kalmanje's (2004) CBCP proposal is to be revenue neutral, through issuance of travel budgets, transport economists were asked to rank a set of alternatives for uses of "excess revenues."[5] Maintaining existing infrastructure and/or adding capacity were the most preferred choices. Next was development of alternative modes, such as transit. Those who strongly favored transit were not interested in reducing gas taxes—and vice versa. Some respondents suggested reducing general taxes via CBCP revenues. There was not much interest in using such revenues to improve air quality.

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[3] Many of the individuals in service industries mentioned that any flexibility or policy changes (in their respective firms) caused by CBCP would be slow to come, since decisions regarding flex-time and toll-reimbursement ultimately would have to come from a firm's corporate headquarters.
[4] Unranked alternatives are assumed to not pose a serious concern for the respondents.
[5] Any unranked alternatives are assumed to hold the lowest ranking.

The question of revenue use was approached cautiously by policy makers, all of whom hail from Texas. Several alluded to Texas HB3588, which went into effect in September 2003 with very specific guarantees[6] regarding application and use of standard road tolls. They believe that Texas toll revenues must be used to cover the construction costs of new transportation infrastructure, much like tolls from IH-30 between Dallas and Fort Worth many years back. One mentioned that the revenues from a priced corridor in a particular region would more or less need to stay within the region, and each tolled corridor needs to have a non-tolled alternate route.

2.2.6 Public Response: Expert Opinions

Policy makers worried about the best way to propose CBCP, since any restrictions on mobility are bound to generate controversy. A commercial user felt public acceptability would be greater for a simpler policy. For example, people who are not used to even flat tolling might not be very comfortable with a CBCP policy. All policy makers felt that public acceptability could be rather low, despite the logic of CBCP's design and any congestion-reduction benefits the public would experience. However, the transport economists felt that CBCP could be more acceptable than other pricing strategies.[7]

When experts were asked whether collecting non-congestion-related tolls (to finance infrastructure) together with CBCP might create any problems, the general response was that the public needs to be well informed as to how congestion toll revenues will be redistributed (as travel budgets), while infrastructure tolls would be withheld for roadway maintenance and improvements. Respondents were apprehensive that introducing too many tolls at once might confuse the public. A transportation engineering professor suggested replacing the gas tax with a flat toll and introducing CP in the form of off-peak and low-use road *discounts*, so as to increase public acceptability. However, one transportation planner felt that the infrastructure toll was likely to be much larger than a simple replacement of the current gas tax would suggest. A few respondents hinted at using standard CP as a means of financing new infrastructure, delaying the implementation of CBCP until the initial investment is recovered. But such a strategy has associated equity problems (e.g., why should only peak-period users be charged?), and maintenance costs remain significant.

Participants were asked which pricing policies (including CBCP) they would consider first for their regions, and HOT lanes were a favorite, primarily due to public acceptability and political feasibility. CP was also a prominent choice, but some respondents indicated that CBCP could be a better option. They recognized the potential of CBCP to gain greater public support than CP. Other responses included flat tolls, managed lanes, ramp metering, FAIR lanes, parking charges and area-wide roadway pricing (like in London). A commercial user suggested trying flat tolls before implementing CBCP, so as to increase public awareness/acceptability. Flat tolls on a portion of the network may prove a useful transition policy for CBCP across the remaining network's principal corridors.

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[6] HB3588's Chapter 227 Sec. 370.174 describes the use of surplus revenue, to reduce tolls, assist in other local transportation projects, or deposit into the State's Mobility Fund.

[7] Kockelman and Kalmanje (2004) found public support for CBCP in Austin (24.9%) to slightly exceed that for flat tolling (24.2%). Support for CBCP was higher (50%) among persons already familiar with CP. Thus, education may be the key to generating popular acceptance.

2.2.7 ETC Technology and Configuration

Toll technology experts across the U.S. responded to a series of technology and CBCP-related questions. Experts recommended technologies that could function over a wide range of frequencies/protocols. Modular technologies were advocated, so that the latest modules could be incorporated as needed. Based on the responses received[8] and our own survey of existing ETC practices, Radio Frequency (RF) tags are recommended.[9] Automated number plate recognition (ANPR) technology would be used for enforcement with cameras that capture pictures of license plates of vehicles that fail to relay a usable tag ID[10]. Respondents recommended placing ETC units at freeway entrances and exits unless such ramps are rather frequent (i.e., every two miles or less). In that case placing antennas/readers at two-to-four-mile intervals might be more cost effective. Placing antennas/readers at entrance and exit ramps (on an access-controlled highway) would involve fewer transactions, but if one of the readings is flawed or missing, the trip record is lost. Frequent antennas/readers involve more transactions, but even if data from one reader is missing, data from other readers can be used to determine the appropriate toll.[11]

2.2.8 Dynamic Pricing

In the case of dynamic pricing, tolls vary with traffic levels, somewhat unpredictably. One transport economist indicated that travelers may not be comfortable with this approach. Another suggested that people might accept dynamic pricing if they have an alternative, non-priced route. Also, in the absence of such an option, pre-fixed (by time of day) variable pricing might be a better option, rather than truly traffic-dependent, dynamic pricing. Most toll technologists felt that changing pre-determined tolls every fifteen to thirty minutes based on expected congestion levels should be acceptable to the traveling public. But some expressed concern that changing tolls so often and in a predetermined fashion could cause unusual traffic disturbances (such as queues forming just upstream, on shoulders and side roads, in the minutes before a toll reduction). Suggestions on toll levels ranged from 12 cents to 20 cents per mile during congested

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[8] Many respondents recommended radio frequency (RF) tags because of their easy availability and cost effectiveness. GPS was also quite popular since it is likely to be a common on-board technology in future vehicles. However, skepticism existed over GPS as an effective technology since it recently did not prove successful in Germany's truck tolling program 'TollCollect.' A few respondents recommended dedicated short range communications (DSRC) transponders, but an ETC company representative indicated that such transponders cost hundreds of dollars while new RF tags cost as little as \$5–\$10 each. Respondents did not seem very concerned over the issue of the current technology becoming obsolete with the advent of cutting-edge technologies like DSRC and 5.9 GHz radio frequencies.

[9] Vehicles would be identified by RF tags (transponders) mounted on their windshields and roadside antenna-readers. Each lane would have an RF antenna, connected to a reader. The reader sends a signal to the RF tag on the vehicle through the antenna, letting the RF tag know that it should communicate. The tag then sends a unique vehicle ID number.

[10] If the AVI system were to detect a vehicle without an on-board unit (OBU) or with a faulty OBU, it would trigger a computer to save the image of the particular vehicle license plate. Information regarding the owners of such vehicles could be obtained from the state's vehicle registry. The major problem with license plate recognition (LPR) is that some inaccuracies that require manual verification. Causes include a lack of plate standards, dirty and damaged plates, incorrect plate mounting, differences in vehicle design and plate position, and ambiguity/similarity in letters/numbers (e.g. London VES errors arose from the similarity of letter O and number 0).

[11] We have assumed ETC units to be placed at three-mile intervals on average for technology cost estimation.

situations[12]. Respondents felt that variable message signs (VMS) boards should be placed well before an intersection (i.e., one to miles miles in advance, depending on existing signage) so as to provide enough time for drivers to perform any lane-change maneuvers necessary to access both tolled and non-tolled facilities. The respondents mentioned message clarity and information in languages other than English as important for VMS.

2.2.9 Issues with User and System Data

Policy makers and toll technologists were both asked about user data issues. While the former seemed comfortable using vehicle license information from state records as needed, a few were against a policy. A couple of toll technologists suggested storing credit card information (so as to automatically replenish accounts with cash credits). Those against it cited the possibility for fraudulent use of such information and unease over being automatically billed for a dynamically priced product. Both groups also were concerned that people might not trust the government with their credit card information; hence, a third party might be needed for this purpose. Irrespective of the type of information stored, respondents felt that data storage would be very burdensome for the associated agency. A policy-maker also expressed concern over people moving into and out of the region, claiming that keeping track of the thousands of movers each month would be "untenable." Respondents felt that social security number information should not be needed.

Respondents felt that a customer service center would be needed to handle problems regarding faulty tags, incorrect billing, account information and corrections, and other credit dealings. One suggested budgeting for one customer service hour per month for every 100 drivers using the system.

2.3 Summary

This survey of commercial users, policy makers, toll technologists, and transport economists revealed a series of useful, and sometimes conflicting, opinions. Commercial users and transport economists generally were quite positive, while the policy makers were a little skeptical. Respondents considered administrative burdens to be a key issue for a CBCP policy, whether in simply storing trip and toll information or in allocating credits to road users.

The allocation of toll revenues is a key issue, since public opinion largely depends on how revenues are used. If not all CP revenues were to be returned to the travelers, the respondents wanted those monies mainly to maintain existing roadway infrastructure and add capacity. Investing in transit was the next most favored alternative. While generally receptive to the idea of CBCP, many respondents were concerned about public opposition to tolling, privacy issues, record keeping, travel budget allocation, and equity issues. Respondents did not favor equal credit allocation to all residents and were mainly concerned about the allocation of travel budget to individuals. Compact land development was expected, but there was no consensus regarding the impact on state and local economies (though this impact was expected to be only marginal).

The toll technologists recommended using RF tag technology for CBCP, with a cost likely to be as low as \$5.00–\$10.00 per on-board unit (OBU). They also mentioned global positioning

[12] While marginal cost pricing (MCP) of roadways, as a function of traffic levels, is theoretically best, such dynamic pricing adds uncertainty to travel options and may not be tenable. Some balance between predetermined tolls (by time of day) and flexible tolls may be best in practice, as done in the case of SR91 (OCTA 2003).

system (GPS) as a potential technology and referred to technologies like direct short-range communications, and commercial vehicle information systems and networks. They suggested ANPR for toll enforcement, though a few privacy concerns were expressed. Agency-stored user information should include OBU information, user names and addresses, vehicle registration data, and possibly credit card information (as an option). Respondents suggested storing system performance data before and after policy implementation.

Commercial users who depend heavily on timely product and service delivery indicated that they would be very willing to pay a premium to guarantee such deliveries, and office-based commercial users indicated a willingness to support some congestion mitigation policies as part of an effort to reduce regional pollution levels. Nearly all employers did not anticipate paying for CBCP-related charges incurred by their employees, which would mean that, at least on a regional level, such charges would be paid directly by system users and not their employers. As the outsourcing of transportation and distribution becomes more ingrained in business models, incentives for timely delivery no longer reside so much in these commercial entities but in their shippers and couriers. This trend may undercut incentives that reduced congestion levels might bring to many commercial users.

Overall, it seems that there is strong support for tolling among experts and policy makers to manage congestion based on current technologies. The feedback from these experts and stakeholders was used to refine the CBCP policy recommendations. Chapter 8 gives a set of such recommendations for the implementation of a CBCP policy.

While the set of respondents used here is not a representative sample and, notably, does not represent the public at large, it reflects a great many perspectives and opinions of many highly valued experts in the transportation pricing field. Future surveys of the DFW public could illuminate the region's perception of such a policy even more (see Appendix A2 for such a survey questionnaire). In the meantime, Kalmanje and Kockelman's (2003) Austin survey results provide a valuable public perspective, and questions from Podgorski and Kockelman's (2005) state-wide surveys (including a follow-up survey described in Podgorski 2005) provide another perspective.

As indicated earlier in this synthesis, the stakeholders and experts held different opinions about the use of CP revenue. Similarly, the authorities in charge of the revenue might have different plans for investing the revenue. Various alternative uses of CP revenue were explored in this study, including tax-reduction, capacity addition/maintenance, investment in transit, and crediting travelers. These are discussed in detail in the next chapter.

3. Evaluation of Alternative Uses of Congestion Pricing Revenues

3.1 Introduction

Congestion pricing (CP) has been suggested by economists and practitioners around the world as a solution to worsening traffic. While CP offers several clear benefits, the success of any roadway pricing policy depends on how the generated revenues are used. And experts differ on the best uses for such revenue. Unless revenues are channeled back into the transportation system, Hau (1992a) feels that a CP policy is unlikely to be publicly supported. Small (1992) believes that those otherwise harmed by CP should be the primary beneficiaries of its revenues (e.g., travelers forced to choose other modes appreciate transit investments). Practical public policy almost demands that congestion-related revenues be used to benefit the traveling public, (rather than, e.g., schoolchildren), though a significant portion of other transport fees (e.g., gas taxes) are often used for non-transport expenditures.

Revenue use decisions are likely to be affected by a variety of criteria. These may be economic or fiscal in nature, equity-related, and/or based on social welfare. Economic efficiency is often a key criterion, at least in theory. Litman (1996) explains that *economic efficiency* refers to maximizing net social benefits, regardless of whether these monies go back to transportation uses. The purpose for which the revenue is used is immaterial—so long as it is the highest and best social use is made (e.g., using CP revenues to reduce income taxes). Putting such theory aside, Wachs *et al* (1994) recommend that CP revenues *not* support general public programs, like social services, since people then may perceive CP as another form of taxation. Goodwin (1989) notes another important issue, which also affects public perception: whether or not *regional cross-subsidization* should be allowed, in order to achieve greater economic efficiency—in other words, whether revenues from one area may be used in another, on a project that offers greater social benefits. Current Texas policy suggests that this is not a top option (see Texas HB3588).

Taking a different approach, Ferrari (2002) showed that optimal tolls (recognizing both congestion and roadway costs) are independent of *fixed* roadway costs, and depend largely on the marginal cost of public funds and motorists' willingness to pay. When both these values are relatively high, a road's revenues may exceed its construction and operation costs. He recommended that such surplus funds be made available for other uses, such as other roads, in other regions.

The issues for revenue generation and use are many, and the options varied. This chapter details various CP revenue uses and the different considerations in determining their best use. It considers actual practices and examines factors that make CP revenue use more publicly palatable. The consensus seems to be that, rather than using revenues for a single purpose, a multipurpose approach can provide the greatest welfare gains, benefiting a variety of interest groups.

3.2 Equity Considerations

In this section, various equity considerations that govern CP revenue are discussed. Equity refers to fairness in the distribution of program benefits and costs, such as the level and application of CP tolls, and the distribution of revenues and time savings (Giuliano 1994). Evans et al. (2003) discuss both horizontal and vertical equity. While horizontal equity relates to equivalent (or "fair") outcomes for similar individuals/groups, vertical equity relates to groups that are dissimilar, as in income levels. In the case of CP, horizontal equity requires that similar persons benefit similarly, though this principle can apply geographically, as well as across users and non-users with similar travel needs. In contrast, vertical equity requires that revenues be distributed according to need, providing additional benefits for disadvantaged groups, such as low-income single-parent households. To promote vertical equity, CP revenues might best be used to fund transportation alternatives, such as bus lines, or to provide cash payments to low-income individuals. In practice it is difficult to keep track of a policy's costs and benefits across different groups; hence, it is not possible to maintain perfect vertical equity. And Litman (1996) notes that measuring impacts and gauging vertical equity with respect to income levels is imperfect, since individuals with the same income often have very different travel needs. Finally, Viegas (2001) brings up the issue of *longitudinal* equity of impacts, over time, and argues that even if horizontal and vertical equity are achieved, pricing a previously unpriced corridor clearly is inequitable, in a longitudinal sense.

Equity is a key consideration for any policy impacting a large segment of society. While CP is rather easily justified based on an economic efficiency argument, its equity impacts are open to debate. The above discussion illustrates several aspects that such a debate might entail. In general, standard congestion pricing (without redistribution of revenues) benefits those who highly value their travel time, while harming most others (Arnott et al., 1994; Hau, 1992; Evans, 1992). It is this issue that *credit-based* CP policy intends to address, by returning revenues to all travelers, in a largely uniform fashion. In the following sections, travel cash "credits" and other uses of CP revenue are discussed in detail.

3.3 Revenue Uses

3.3.1 Infrastructure Improvements

It may be politically acceptable to use CP revenues for construction of new roadways and add capacity to existing roadways, since these improve service quality for both toll road and non–toll road users. However, it may not be prudent to add capacity where right-of-way acquisition, construction and/or environmental costs are high (Litman 1996). In addition, the Pigou-Knight-Down Paradox states that attempts to relieve the roads of congestion by increasing capacity can be undermined by latent or "pent-up" demand. Moroever, Braess' Paradox recognizes that addition of new links in a network of roads could increase total travel times, though this is rather rare in practice (Arnott and Small 1994).

Small (1992) feels that using CP revenues to add capacity and/or maintain existing capacity would help gain support for CP—from the traveling public, transportation officials, the highway industry, and others. However, Levine and Garb (2002) argue that using revenues exclusively for such purposes would largely benefit relatively wealthy drivers, with their high values of travel time (or, really, greater ability to pay), while adversely affecting others, especially low-income drivers. Thus, to summarize: while there is likely to be significant support for roadway improvements, it is not evident that these represent the highest and best use of congestion toll revenues.

3.3.2 Tax Reduction

CP revenues could be used to reduce or replace a variety of existing taxes. While not necessarily equitable, such use may be the most realistic method of returning CP revenues in a relatively uniform fashion to the traveling pubic while gaining support for CP policies. Harrington et al. (2001) found that public support[13] for CP increases 5–10 percent if a substantial part of revenues is returned to the public as tax reductions. For additional discussion on public support for various revenue uses, readers may refer to Appendix C1.

Reducing or replacing gasoline taxes is one means to achieve tax reductions. Small (1992) argues in favor of gas tax reductions. He notes that (1) gas taxes are a weak indicator of road use (since fuel efficiencies differ widely across vehicle types, and thus gas taxes paid do not track one's VMT too closely) and (2) improvements in vehicle efficiency and introduction of alternate fuels have undermined the tax's effectiveness. He also believes that reducing gas taxes in the U.S. will not be an incentive for people to drive more, since these represent a relatively small portion of vehicle operating costs[14]. However, there is still a need to pay for road construction and maintenance, and in the past, gas taxes have proved a rather effective and administratively simple mechanism to fund such outlays.

Vehicle registration and licensing fees offer another opportunity for tax reduction. However, just like gas taxes, these do cover certain related costs borne by the government (e.g., maintaining records on vehicles and their owners, for assistance in policing efforts) and may not represent the most efficient or equitable option for tax reductions. In a study of Southern California residents, Small (1992) supported the reduction of gas taxes over the reduction of registration and licensing fees with the congestion tolls. This was because vehicle license fees in California are partially deductible in federal income taxes, so reducing license fees would increase federal tax liabilities, thus, to some extent negating the benefits of license fee reduction.

Small (1992) recommends that policy makers consider using congestion tolls to replace taxes that presently finance transportation projects. For example, in most places, local roadway infrastructure is largely funded through property taxes. A reduction in these could reduce the inefficient subsidies that currently exist. It is more efficient to charge directly for use/consumption of a good, rather than subsidize certain goods through the taxation of others. In this way, the market signals—through prices—are direct and consumption is more optimal. Indeed, charging for one's impacts/consumption is whole the motivation behind CP (where drivers are expected to pay the cost of delays imposed on others).

Of course, those who pay congestion tolls are not the only ones affected by CP. CP also affects people who, in order to avoid such tolls, no longer use the priced corridors, and thereby are inconvenienced. External costs of motor-vehicle use, such as certain crash risks, air and noise pollution, and reduced mobility for non-drivers (OTA 1994), further complicate the situation (Litman 1996). In addition, road pricing can cause traffic to spill onto adjacent, unpriced corridors, thereby affecting local streets and their residents. Horizontal equity may require that all such affected groups be compensated before compensating system users (Repetto et al. 1992).

[13] The study surveyed residents of Southern California and hence the findings might not be applicable to Texas.
[14] The average cost of driving a car is 56.2 cents per mile (AAA 2004). The average gas tax is 42.7 cents per gallon (API 2004). The average passenger car's fuel economy is 22 miles/gallon (BTS 2000). So this gas tax amounts to around 3.5% of driving costs.

Reduction of income taxes would benefit many individuals, but it is not designed to address the negative externalities of road transport. Moreover, Verhoef et al. (1997) found that using road pricing revenues to reduce income taxes was not very popular with residents of the Randstad Area of the Netherlands. Of course, Texans may differ. However, Texans do not pay state income taxes, so a reduction in those is not one of the state's options.

In related work, Parry and Bento (2001) estimated that welfare gains from income tax reductions exceed those due to transit subsidies and lump-sum transfers to all tax payers. Though tax reductions and transit subsidies both increased labor supply, the increase was greatest when cutting the labor tax. Parry and Bento did not consider revenue use in the reduction of gas taxes or vehicle registration and licensing fees, however. Those taxes were expected to have minimal effects on labor supply, so they were not of primary interest in Parry and Bento's work (which is concerned with the labor-supply effects of CP, since such tolls affect a great many commuters, on their way to and from work). However, they too may offer significant welfare benefits. In conclusion, reducing taxes or other driving costs may be a problematic strategy. It is indirect and may not be the best use of revenues. However, it offers a manner of "crediting" many individuals, across a region, with minimal administrative burden.

3.3.3 Investing in Non-auto Alternatives

As discussed earlier, individuals who change their travel patterns (destination, mode, route, and/or departure time) to avoid congestion charges pay indirectly, through inconvenience. Their absence on the priced roadways also alleviates such congestion. For both these reasons, one can argue that such user groups also should benefit from CP revenues. One way to address this is by funding alternative modes of transport, such as transit. Good transit services will attract more users, and increased ridership may permit further service improvements (such as higher service frequencies and newer transit vehicles). CP is likely to increase the demand for transit. Since transit is largely subsidized, meeting that demand will require additional subsidy. CP revenues are likely to be needed for such improvements in the transit system, in order to avoid forcing people to drive and overwhelming the transit system. Almost half of the transport economists contacted as a part of this research project suggested revenue from CP to be invested in transit. Komanoff (1997) suggested that transit investment is compelling in areas with well-established transit facilities. For cities where transit has very little or no base, he suggests per-capita rebates or reductions in regional sales taxes. For cities in between these extremes (e.g., those with functional but heavily subsidized transit services), a combination of both approaches could be used.

Apart from transit-based development, Small (1992) suggests that revenue could be used for carpooler-matching services, better pedestrian facilities, and safer bike lanes. These applications should gain support from environmentalists and those interested in such mode choices.

Thus, transit and other non-auto applications could be very viable uses of CBCP revenues. These offer tangible benefits in terms of congestion relief and air quality improvement, while spreading welfare benefits across a wider segment of the community. However, where transit is not a reasonable option for most travelers, tax reductions and other uses may offer better opportunities for revenue use.

3.3.4 Crediting Travelers

In a congested region CP transfers a great deal of money from the traveling public to tax collecting authorities. In the case of public roadways, this money really does not belong to the authorities. Congestion tolls are to ensure that travelers recognize the true cost of their trip-making (i.e., the cost of delays imposed on fellow road users). While a certain portion of such revenues are needed to cover the costs of a CP program (e.g., roadside detection devices, variable message signs, toll collection, and general program administration), the rest arguably belongs to whoever truly owns the road. In the case of public roads, this is "the public" at large (or at least, one can argue, those who pay the taxes that fund transportation infrastructure).

Of course, if users are reimbursed in proportion to how much they pay or how much they drive, there is no incentive to change one's travel behavior. So revenues should be returned irrespective of whether or not an individual pays any fee. Paying a higher amount to users who drive more (and hence pay more) or have higher vehicle ownership actually provides an incentive for people to drive more or own more vehicles, which is not desirable.

As discussed earlier, equity considerations may compel compensation of a variety of groups[15]. For such cases, various credit distribution strategies may be worthwhile. These include Small's (1992) commuter credits and Kockelman and Kalmanje's (2004) credit-based congestion pricing. They also include the idea of crediting special groups, such as low-income workers, disabled travelers, and/or persons living in heavily priced zones (such as those residing within London's cordon line, who pay just 10 percent of the cordon toll).

Small (1992) proposed a travel allowance for all *commuters*. He recommended a fixed amount per month per employee, regardless of mode or time of travel so that CP incentives (i.e., reduced driving on congested roads) would not be undermined. Taking a different approach, Parry and Bento (2001) recommended that income taxes be reduced, to offset any CP-related labor supply restrictions. (Their work was discussed earlier, in the section on Tax Reduction.)

In Kockelman and Kalmanje's (2004) work, the term "credit" refers to a monetary cash out. Every licensed traveler living in the designated "priced region" is given a monthly allowance of "credits" to spend on travel—or on anything else. Those in the driving population who exhaust their credits while paying congestion tolls will pay out of their pocket to keep driving, beyond their allowance. Those who save their cash credits can spend them. The value of each month's travel allowance depends on the total revenue collected that month. Revenue-neutrality is maintained by returning all revenues, after covering policy administrative costs (which are not insignificant at this time).

Of course, for special groups, extra and fewer credits can be allocated. For example, low-income working parents may be eligible for additional credits, while those under 20 years of age and/or unemployed may receive less. Credit distribution is a key policy question. Such distribution, however, can require a great many resources, to avoid fraud in application for and receipt of credits, particularly if these are in the form of cash. For this reason, tax reductions and transportation investment may be more practical.

[15] Equity does not mean that everyone be compensated for damages. If market perfections, such as congestion, presently are benefiting certain groups that do not deserve such benefits, one cannot argue that such persons deserve compensation on the basis of equity.

3.3.5 Other Revenue Uses

Revenues also may be used to benefit businesses adversely affected by CP. For example, central-area businesses might not enjoy as many customers as before, because of increased travel costs to downtown. Small (1992) suggested that cities repair streets and provide better lighting, pedestrian facilities, street landscaping, and transit-related infrastructure in such areas, so that affected businesses perceive some benefits. This measure also will appeal to residents of the areas where such improvements are made.

Employers also could be encouraged to organize vanpool and buspool programs for their employees, using CP revenues to subsidize vehicle costs. Price (2002) has discussed successful vanpool strategies adopted by various Southern California companies. And Small (1992)'s idea of commuter travel allowances could be applied as discounts for vanpoolers and carpoolers.

Gee and Hannemann (2002) proposed compensation of persons negatively impacted by CP in the same "dimension" as the impact, for equity and political reasons. For example, if low-income drivers are priced away from a certain area (such as the downtown) on weekdays, they could be permitted free parking in the same area during weekends.

CP revenues also could be used to improve air quality. Certainly, traffic demand reductions (due to congestion pricing) will certainly achieve this, to some extent. In regions where air quality is a serious concern, CP revenues may be used to pay owners to scrap older, high-emissions vehicles, and to purchase roadside detection devices, in order to identify high emitters, for example.

There are many other purposes to which CP revenues could be reasonably applied. Those that best meet the aspirations and needs of a community will differ across regions. A combination of such uses also may be worthwhile.

After considering the various populations affected by CP, Small (1992) suggested combinations of revenue allocations in order to offset certain impacts of such policy. He proposed that roughly one third of revenues be used to reimburse certain travelers (e.g., commuters, through travel allowances), another third go to reducing transportation taxes (e.g., gas taxes), and the final third go toward improving other transportation services (i.e., transit). Goodwin (1989) had proposed using revenues for both highway and transit improvements, as well as tax relief or increased general expenditures. But Small (1992) suggests that significant spending on new projects will not be needed, since CP will tame demand to such a degree as to render current capacity largely sufficient.

3.4 Conclusions

This chapter examined various CP revenue use options. In general, experts emphasize that revenues should be spent so as to generate public support while enhancing public welfare. However, the details of their recommendations do diverge. Some advocate tax reduction, others advocate travel allowances. Some recommend network expansion, others recommend transit improvements. Caveats apply in all cases, and a variety of uses may be undertaken at once. For example, sales tax reductions apply to a region's population rather globally, while income tax reductions primarily benefit workers (and thus commuters). Travel allowances may go to all licensed drivers, just commuters, or just disadvantaged travelers; however, such allowances can entail substantial administrative costs. Roadways may be expanded through addition of lanes or addition of links, or they simply may be better maintained. Transit expenditures may be pointless in regions where transit is not a reasonable alternative; in such cases, transfers or travel credits may make the most sense. Of course, the operational and administrative costs of a CP policy are not insignificant, and those costs must be covered. The magnitude of such costs is being explored in this project (TxDOT Project #0-4364). However, in order to keep administration costs low, certain policy options may be preferred. For example, rather than distributing cash credits widely (as under credit-based CP), tax reductions may be pursued.

Since different populations experience different impacts, it may be wise to apply CP revenues for various purposes, thus benefiting a wide segment of society. For a discussion of current field practices in use of CP revenues, please refer to the Appendix C2. Appendix C3 summarizes user opinions of selected road pricing projects. The choice of such purposes ideally should depend on expectations of policy impacts, by a person's home location, income bracket, and travel needs, since impacts will differ. However, such predictions are complex and uncertain. Please refer to section C for a discussion on political acceptability of revenue use. Thus, after considering all the options discussed herein, it may be best to stick with a broad-based tax reduction policy, travel credits for certain disadvantaged groups, and capacity expansion in locations most affected by continuing congestion, even after CP is implemented in a region.

As mentioned in the previous chapter, this study surveyed experts and stakeholders related to CBCP application in Texas. The questionnaire asked experts in the field of transport economics to rank a set of alternatives for use of CP revenues, in excess of those used for travel credits/allowances. Most respondents wanted the additional revenue to be used to maintain existing infrastructure or to add capacity. A lower priority was to develop other modes of transport, such as transit. There was not much interest in using such revenue to improve air quality. Those who strongly favored transit improvement were not interested in reducing gas taxes and vice versa. Some respondents suggested reducing general taxes through CBCP revenues (or CP revenues, really). Appendix C4 tabulates the ranking experts assigned to these alternatives.

Next, the study aims at predicting the traffic and air-quality impacts of a CBCP policy. This involves travel demand model estimation and application. Traveler behavior was modeled using joint destination-mode choice models for different trip purposes, estimated from the Dallas–Fort Worth household survey and transit on-board survey data. The next chapter discusses the model estimates and its application to the DFW region.

4. Travel Demand Model Estimation and Application

4.1 Introduction

Implementation of any major transportation policy involves system-wide impact assessment. In this study, the short-term and long-term traffic impacts, air-quality impacts and welfare changes resulting from a possible CBCP policy are predicted. This evaluation involves modeling traveler behavior and travel demand as a part of the four-step transportation planning process. Destination choice models form an important part of this process, finding application in the trip distribution stage. These models predict the trip-end (attraction zone) choice of an individual traveler. The factors that determine this decision are believed to be the zonal characteristics of the attraction zone, impedance to the zone (determined by cost, travel time, and other level of service [LOS] variables), and traveler demographics. Many MPOs still use gravity models, which are unable to accurately capture the effect of demographics on destination choice. Improved forecasts of destination choice enhance evaluation of transportation policies and produce better estimates of traffic conditions and travel distances, which are key to emissions estimation. This study uses demographics to model destination choice, in addition to zonal attraction characteristics and impedance values.

In reality, travelers usually tend to choose their trip destination, mode, and departure time in a simultaneous fashion, since these choices are related. Therefore, destination-mode-departure time joint choice modeling may be a better option than modeling these choices separately. However, data constraints prevented estimation of such a model for the Dallas–Fort Worth (DFW) region. There were a very limited number of transit and walk/bike trips and no departure time information for transit trips in the transit on-board survey data. Also, there were only two travel time and cost matrices (corresponding to peak and off-peak) to start model calibration. So, modeling choice of five time periods using limited information was not reasonable. For these reasons, the study modeled destination and mode choices jointly, and by trip purpose.

The joint destination-mode (DM) models were applied to the DFW region. In addition to the status quo, two scenarios were simulated: Marginal cost pricing (MCP) on freeways, and MCP-on-all-roads, in the short run and the long run. Travel demand model (TDM) application involves using the models and appropriate information from the survey data to obtain the origin-destination (OD) trip tables and assigning them to the network to obtain link flows, travel times, and travel costs. This chapter discusses various steps in the application process.

The following section gives an overview of the model estimation procedure. This is followed by the model estimates and its interpretation. The model application to the DFW region is summarized next. This chapter does not address the details of the above procedures, which are discussed in Appendices D1 and D2.

4.2 Model Formulation

The destination choice component of the model used in this study is taken from Daly's (1982) model. In theory the number of destination choices available to an individual is equal to the total number of zones in the study area. However, considering all the zones in the choice set is computationally intensive. If the error terms are assumed to be identically and independently distributed (IID), then the choice model can be estimated using a subset of the actual choice set

(McFadden 1978). Pozsgay and Bhat (2002) found that destination choice model estimates based on choice sets of 10, 20, and 30 alternatives differed very little. Thus, eight randomly selected zones along with the chosen zone form each traveler's destination choice set of nine alternatives in this model's calibration.

The analysis considers four modes: drive alone (DA), shared ride (SR), transit, and walk/bike (WB). The overall choice set usually consists of thirty-six choices based on nine destinations and four modes for each destination. (Some modes were not available for some origin-destination pairs, however.) This feature of a limited choice set for some travelers/trip origins was incorporated in the model estimation. This is discussed in further detail in the following section on data assembly. The analysis developed models for three trip purposes: home-based work (HBW), home-based non-work (HBNW), and non-home-based trips of all purposes (NHB). A multinomial logit (MNL) structure was used.

Transit on-board survey, also provided by the North Central Texas Council of Governments (NCTCOG), was added to the household survey data so transit trips are better represented. The trip origin and destination ends were recoded as production and attraction ends and demographic information was appended. Additional records with the same production end and random attraction ends were created for each trip record and appropriate LOS data was appended from the relevant LOS files. Zonal characteristics were also appended and then weights computed based on mode shares in the household survey and the current data set. Zonal characteristics—land area, population, and total employment—were included in the model in a log linear fashion and the coefficients on these variables constrained to be positive. NCTCOG provided income information in three categories at the zonal level and hence indicator variables corresponding to the income categories were used in the models. Cost matrices for DA and SR trips were computed by assuming an operating cost of 30 cents/mile. WB times were computed assuming a speed of 5 mph, and the costs were assumed to be zero. The values of travel time (by income group and trip purpose) were constrained in the joint DM choice models. The logarithm of generalized cost was used in the models since it fit the data better than a linear form. All these are explored in more detail in Appendix D1. The following section presents the joint DM model estimates for various trip purposes.

4.3 Joint Destination-Mode Choice Model

The MNL model for joint DM choice model for the three trip purposes is given in Table 4.1.

Table 4.1 Estimates for the joint DM choice model

	HBW		HBNW		NHB	
Parameters	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Alternate specific constants						
Shared ride	-2.6395	-22.2	-0.8886	-15.0	-1.2901	-39.0
Transit	-0.7356	-2.3	0.2835	1.2	-3.5301	-9.0
Walk/bike	-1.2274	-4.3	-2.2178	-17.0	-2.8672	-25.8
Demographic variables						
Medium Income dummy						
Shared ride	-0.1774	-1.4	0.2073	3.3	-	-
Transit	-0.9249	-2.2	-1.4137	-3.6	-	-
Walk/bike	-0.6301	-1.6	-0.4737	-2.9	-	-
High Income dummy						
Shared ride	-0.2303	-1.7	0.3414	5.2	-	-
Transit	-2.3318	-3.2	-4.5134	-2.4	-	-
Walk/bike	-0.8417	-1.5	-0.5193	-2.8	-	-
Zonal attributes						
Zonal attraction	0.8057	-7.8	0.5142	-13.2	0.5978	-9.7
Land area	68.6966	27.9	127.8554	18.0	82.2695	13.4
Population	0.0121	-6.9	0.3961	-5.9	0.3604	-6.6
Employment	1	N/A	1	N/A	1	N/A
Log of Impedance	-1.9533	-50.9	-2.4534	-82.3	-1.9682	-66.9
Impedance interaction terms						
Veh Ownership >= 1 per person						
Drive alone	-0.0489	-7.0	0.0743	11.9	-	-
Shared ride	-0.1827	-9.2	-0.0538	-3.9	-	-
Transit	-0.4096	-3.1	-0.4275	-3.1	-	-
Walk/bike	-1.0643	-2.2	-0.3260	-2.1	-	-
LL at convergence	-8676.1		-15857.3		-8660.2	
LL at constant	-15512.6		-35350.4		-16720.2	
Number of cases	10551		15224		7014	

The coefficients on the mode-specific income category dummy variables indicate that higher income HBW travelers prefer to drive alone. However, for HBNW trips, SRs systematic utility is estimated to increase with income. The negative coefficients on the interaction terms of generalized cost and vehicle ownership indicators (for all modes) indicate that individuals in households with more than one vehicle per person are not willing to travel longer to work by any mode. However, for non-work purposes such individuals are willing to travel farther when driving alone. The above model was able to explore traveler behavior as a function of demographics to a limited extent, because only a two-way distribution of income and vehicle ownership at the zonal level was available. (This was chosen over the two-way distribution of household size and income that also was made available by NCTCOG.) The goodness of fit measures (likelihood ratios) of these models are discussed in Appendix D1.

4.3.2 Travel Demand Model Application

As discussed in the previous section, joint DM choice models were estimated from the DFW household survey data. Three scenarios were simulated: Status quo, MCP-on-freeways, and MCP-on-all-roads. The zonal productions for each trip purpose, provided by NCTCOG, were available for six demographic groups based on income category and vehicle ownership. They were split corresponding to five time periods based on factors developed from the household survey. To account for walk-bike choices the productions were increased by a factor based on walk-bike mode shares. The joint DM choice model was used to compute the probabilities of different mode-destination alternatives, which were used to compute the Production-Attraction (PA) trip tables. Trip return rates and average vehicle occupancy information, obtained from the survey, were used to obtain the OD trip tables from the PA matrices. OD trip tables for different trip purposes were aggregated to give OD trip tables for each time period and vehicular mode (DA and SR).

TransCAD's multi-mode multi-user module using stochastic user equilibrium was used for assigning OD trip tables (weighted) to the 1999 DFW road network. Different networks were used for SR and non-SR trips. The standard Bureau of Public Roads (BPR) formulation was used to define volume-delay relationships on the links. The generalized cost expression for the MCP cases was derived from the BPR function. The method of successive averages (MSA) was used to equilibrate the feedback model rather than using direct feedback. The MSA OD trip tables were assigned to the network to obtain link flows. The MSA travel times and costs were fed back to the joint DM application stage. This process was continued for four feedback loops (or until link flow convergence was reached). TransCAD's gap criterion (for bidirectional link flows) was used as the convergence criterion for MSA feedback.

Since the data was not weighted for demographics, the predicted mode shares differed from the market shares. The mode-specific constants in the joint DM choice models were modified iteratively so as to match the predicted mode shares with the market shares. The travel times used for modeling and the travel times obtained from TDM application for status quo were compared and found not to be very different. The generalized cost computation for different scenarios was discussed. To simulate short run impacts of MCP scenarios, employment locations were constrained (to be the same as those chosen under the status quo). Users were allowed to change (choose) destinations for their HBW trips in the long(er) run.

The analysis assumes inelastic total demand for trips (i.e., trip production is insensitive to travel costs), but that is rather consistent with actual behavior. (See, e.g., Kockelman, 2001.) It also overlooks departure time shifts across the five time periods used. Certainly, departure time choices will be affected by variable pricing; however, those shifts are likely to be on the order of an hour or less, in many cases, so they may not actually shift many travelers out of a time period (since the time periods used here range from three hours to nine hours in length). Finally, static models of travel equilibrium are imperfect. Dynamic traffic modeling is being pursued under this project. It is a labor- and computing-intensive activity that does not yet permit feedbacks to non-route choices. Given enough time, however, these sorts of models are possible

The whole TDM application procedure summarized above (including the assumptions and limitations) is discussed in greater detail in Appendix D2.

4.4 Conclusions

Joint DM choice models predict the trip-end (attraction zone) choice of an individual traveler and also his/her travel mode. Various zonal attraction and demographic variables were used to model choice of 4874 destination zones and four modes for three trip purposes across 32,799 trips in the 1996 DFW household survey dataset and DART on-board survey dataset (provided by NCTCOG).

MNL models with nine destination alternatives (eight randomly chosen) and a non-linear-in-parameters specification was used to model the joint DM choice behavior. The choice set was limited for some observations since all the modes were not available for all OD pairs. Explanatory variables included zonal characteristics, demographics (income and vehicle ownership), and travel time and cost. The VOTTs (by income group and trip purpose) were constrained in the joint DM choice models. The model estimation procedure was coded in GAUSS matrix programming language.

These joint DM choice models were applied to zonal productions in different time periods to give the production-attraction (PA) matrices by mode and time of day. The PA matrices were converted to origin-destination (OD) matrices using trip return rates and average vehicle occupancy for different trip purposes. The OD matrices were assigned to the DFW road network, and the resulting interzonal travel times and costs were fed back to the joint DM choice model application step. A method of successive averages was used as an equilibration technique. Different pricing scenarios were simulated in this process. The entire travel demand model application process is discussed in the next chapter.

The results of TDM application include link flows and speeds for status quo and two MCP scenarios. The predicted traffic impacts of different scenarios were obtained by comparing the vehicle miles traveled, average speeds, delay, and other characteristics for the two MCP scenarios with status quo. Comparison by time period and facility type was done to gain additional insights. The results of all these applications are discussed in the next chapter.

5. Traffic Impacts and Welfare Changes

5.1 Introduction

This chapter compares the results of the three scenarios (status quo, MCP on freeways and MCP on all roads), both in the short run (with employment locations fixed) and in the long(er) run (employment locations flexible). This chapter also explores the welfare impacts of MCP on freeways and on all roads when compared to the status quo. Different user groups exhibit different preferences for travel modes and destinations, as evident in the joint destination-mode (DM) choice models. Estimates of systematic utility functions differ significantly across trip purpose, and travel behaviors vary substantially by location within the region. MCP can make some locations more accessible—and others less accessible. Changes in expected maximum utility of travel choices due to changes in transportation policies offer a holistic measure of resulting impacts on travelers.

MCP-on-all-roads has very high associated initial and recurring costs, as can be seen in Appendix G, and hence is probably not practically feasible in the near future. So, the analysis focuses mainly on the differences between the status quo and MCP-on-freeways. First, the interpretation of the joint DM choice models is discussed. The short-term and long-term traffic impacts in terms of vehicle miles traveled (VMT), mode shares, volume-to-capacity ratios (V/C), vehicle hours traveled (VHT), and predicted speeds are explored. This is followed by a discussion on the welfare changes under MCP scenarios.

5.2 Model Interpretation

Simulating MCP on some (or all) links is expected to affect traveler choices of modes, destinations, and routes. The negative coefficient on the natural log of generalized cost in the joint DM choice models indicates that travelers tend to prefer destinations and modes that have a lower generalized cost (travel time and cost). So, for an MCP scenario the travelers can be expected to try to avoid choices involving higher travel times and/or choices where they have to pay higher tolls (i.e., they might be expected to take the less congested routes and/or choose destinations with lower generalized cost and/or shift from DA to other modes). The extent to which travelers change their travel patterns depends on their income and vehicle availability, which is captured by the models. For example, the negative coefficients on interaction terms between trip impedances (generalized costs) and indicators for vehicle ownership indicate that individuals in households with more than one vehicle per person are not willing to travel longer to work by any mode. However, for non-work purposes such individuals are willing to travel further only if driving alone. The results discussed in this chapter do not quantify the impact of MCP on different user groups, but indicate the effects on the population as a whole. However, the analysis controls for income and vehicle ownership.

The above discussion hints at the traffic impacts that could be expected for MCP scenarios. The following sections compare the TDM application results for various scenarios and report the short-term and long-term traffic impacts of MCP in terms of predicted VMT, mode shift, V/C ratio, VHT, and speed changes.

5.3 Traffic Impacts

5.3.1 Vehicle Miles Traveled

Link flows and travel times obtained from TDM application indicate that the total system VMT for both MCP scenarios (MCP on freeways and on all roads) is predicted to decrease by about 7 percent in the long run, when compared to the status quo. In the short run, VMT for the MCP-on-freeways scenario is predicted to decrease by 7 percent and by about 6 percent for the MCP-on-all-roads scenario. This is expected since travelers are likely to choose nearer destinations and/or shift from DA to other modes. For example, the average trip length is predicted to decrease from 9.63 to 9.09 miles (5.6 percent reduction) for the MCP-on-freeways scenario in the short run. Freeway VMT is predicted to decrease by more than 12 percent for both the MCP scenarios, which is again expected since travelers are likely to move away from the congested freeway links to avoid MCP tolls. In the MCP-on-freeways scenario, VMT on principal arterials (not including freeways) is predicted to decrease (approx. -4 percent) in the short run, but is predicted to increase (approx. +2 percent) in the long run. Observing specific links reveals that in the short run, flows on principal arterial links that serve as feeder routes to the freeways are predicted to fall, while flows on the principal arterial links that serve as alternatives to the freeways are predicted to rise. The overall result is a decrease in principal arterial VMT in the short run. However, in the longer run (when the employment locations are flexible), users chose their employment locations such that the freeways are used less and the arterials used more than the status quo.

In the MCP-on-all-roads scenario principal arterial VMT is predicted to fall by about 2 percent in the short run and by about 5 percent in the long(er) run. This suggests that travelers are likely to try and avoid the MCP tolls on all roads (and are able to do it better in the long run by choosing more appropriate work destinations). Figures E1.3 through E1.10 in Appendix E1 show VMT estimates compared using different criteria. Predicted mode shifts for MCP scenarios are discussed next.

5.3.2 Mode Shift

Interestingly, the models do not suggest any significant mode shifts for the MCP scenarios. In the short run, MCP-on-freeways saw a slight decrease in DA trips (51.4 percent to 50.3 percent) and a slight increase in SR trips (43.3 percent to 43.6 percent) and non-auto trips (5.3 percent to 6.1 percent). The mode shifts for MCP-on-all-roads were not very different from MCP-on-freeways scenario. Very similar shifts are predicted in the long run also. As expected, the mode shift in the peak periods was more than that in the off-peak periods since travelers face more MCP tolls in the peak periods. (See figures E1.11 and E1.12 in Appendix E1.) The predicted mode and VMT differences across scenarios indicate that travelers prefer changing destinations and routes rather than changing modes. An MCP policy may be able to cause an increase in transit ridership (about 15 percent for the MCP-on-freeways case). This has implications for uses of MCP revenues. Next is a discussion on predicted change in congestion levels for the MCP scenarios, in terms of V/C levels.

5.3.3 VMT vs. Volume-to-Capacity Ratios

To discuss how congestion abates, VMT was split into four categories based on the following V/C levels.

1. V/C $\leq$ 0.50
2. 0.50 < V/C $\leq$ 0.75
3. 0.75 < V/C $\leq$ 1.00
4. 1.00 < V/C $\leq$ 1.5
5. V/C > 1.5

According to the Bureau of Pubic Roads (BPR) link performance function (α = 0.15 and β = 4), a V/C ratio of 0.50 reduces speeds just 1 percent from the free-flow speeds. A V/C ratio of 0.75 reduces speeds by 4.5 percent, a V/C of 1.00 reduces speeds by 13 percent, and a V/C of 1.5 reduces speeds by 43 percent. Travel at different congestion levels was measured in terms of a VMT percentage at those different V/C ratio levels.

The models clearly suggest less congested travel for both MCP scenarios, as expected. In the short run for the MCP-on-freeways scenario, VMT at V/C ratios between 1.0 and 1.5 is predicted to fall by about 65 percent and VMT at V/C ratios greater than 1.5 is predicted to fall by a whopping 99.4 percent. (Recall that higher V/C ratios will result in much higher travel delays per marginal traveler, and thus much higher congestion tolls.) In the long run, however, VMT at both the above mentioned V/C levels is predicted to fall by about 73 percent.

For MCP-on-all-roads the predicted reduction in VMT for the two V/C categories is 65 percent and 99.3 percent, respectively, in the short run, and 81 percent and 99.7 percent, respectively, in the long run. Correspondingly, increases in VMT at lower V/C levels (<1.0) for both MCP scenarios suggest shifts from congested to less congested routes. The increase in VMT at lower V/C levels (<1.0) is higher in the long run compared to the short run, indicating better road space rationing in the long run. It is important to note that decrease in VMT do not simply indicate route shifts, but also indicates shifts in destinations and modes. Figures E1.13 and E1.14 in Appendix E1 give the percentage of travel at different V/C levels for the short run and long run,. The reduction in congested travel is most pronounced during the peak period (AM and PM peaks), as seen in Figures E1.15 and E1.16 (in Appendix E1). This could also be described in terms of changes in total VHT, which is discussed next.

5.3.4 Vehicle Hours Traveled and Speeds

If travel were to be measured by total travel time, VHT measures could be compared. Table 5.1 gives the reduction in total VHT and freeway VHT under both the MCP scenarios in the short run and the long run. VHT falls more in the long run for both scenarios. Freeway VHT under both MCP scenarios was less than that for the status quo by about 19 percent in the short run, as compared to about 21 percent in the longer run. This difference was higher for the peak-periods than for the off-peak periods.

Total VMT divided by the total VHT provides a time-weighted average speed. The daily average speeds for the status quo was predicted to be 45.9 mph. In the MCP-on-freeways scenario, the average speeds were predicted to be 45.5 mph and 47.4 mph in the short run and long run, respectively. This suggests a slight dip in the average speed in the short run, and a slight increase in the longer run. In the MCP-on-all-roads scenario, the estimated average speeds were 47.4 mph and 47.9 mph (in the short run and long run, respectively).

Table 5.1 Reduction in total and freeway VMT

Scenario	Reduction in total VHT	% change in total VHT	Reduction in freeway VHT	% change in freeway VHT
MCP-on-freeways				
Short run	173,249	-6.39	251,280	-19.72
Long run	271,467	-10.02	272,903	-21.41
MCP-on-all-roads				
Short run	248,229	-9.16	240,793	-18.89
Long run	313,878	-11.58	271,556	-21.31

Figures E1.17 and E1.18 in Appendix E1 give average speeds by roadway type in the short and long runs, respectively. In the MCP-on-freeways scenario, average speeds are predicted to increase for freeways and decrease for all the other facilities in the short run, but increase for all facilities in the long run. (See figures E1.19 and E1.20 in Appendix E1.) VMT at speeds below 55 mph is estimated to fall, while VMT at speeds over 55 mph is estimated to rise, under both MCP scenarios, indicating a rise in vehicle speeds when MCP is imposed. This reiterates the prediction of reduction in congested travel for the MCP scenarios. In the MCP-on-freeways scenario, it is interesting to note that the VMT in the low-speed brackets (less than 35 mph) is expected to increase in the short run, possibly due to traffic spillovers. However, in the longer run, VMT is expected to decrease in all speed brackets (due to shorter trips/choice of closer destinations, and some mode shifting).

An individual's travel benefits/losses (because of changes in speeds, congestion levels, and choices of destinations, modes, and routes) can be quantified as a welfare change from the status quo. The following section explores the welfare impacts of MCP-on-freeways and MCP-on-all-roads scenarios when compared to the status quo.

5.4 Welfare Changes

User preferences for travel modes and destinations and current residence location determine predicted travel benefits from the CBCP policy. The change in CS is a holistic measure of travel benefits. The change in CS was computed for HBW trips at the production zone level as the difference in the probability weighted systematic utilities of all DM choices for the two scenarios (the status quo vs. MCP scenarios, see Equation 4 in Appendix E2). For HBNW and NHB trips the change in CS was computed at the production zone level as the difference in the logsums of the two scenarios (see Equations 5 and 6 in Appendix E2). Probability weighted values of marginal utility of money ($MU_\$$) were computed for all production zones and user groups for the before and after scenarios and averaged (see Equations 7, 8, 9, and 10 in Appendix E2). The welfare change estimates for all production zones was converted into monetary units using these $MU_\$$. The welfare changes for NHB zones were averaged across all the origin zones to obtain a single value for the region. A weighted average across time periods gave a composite measure of the welfare change for each trip type at every production zone. And an individual's welfare was computed as the number of trips (of each trip type) he/she makes in a day (obtained from the survey) multiplied by the corresponding welfare value. The CBCP budget of $.68./weekday for eligible travelers (as estimated in Appendix G) was added to this value. The spatial distribution of welfare for different user groups for both the MCP-on-freeways scenario is illustrated in Figures E2.1 through E2.6 of Appendix E2.

Welfare gains were predicted to be highest for users near the CBDs. These net benefits are predicted to fall with increasing distance from the CBDs. Average travelers with budgets in all the CBDs and city centers are expected to gain about $.40/day. Users in north DFW (excluding the Denton and McKinney CBDs), the northwest region (to the immediate west of Carrollton), and south DFW (between Cleburne and Waxahachie) are predicted to lose the most, approximately $.30/day. In these regions, the medium- and high-income user groups are expected to lose more than the low-income user group. The northeast and southwest households with at least one vehicle per person are predicted to fare well compared to those with fewer than one vehicle per person. The spatial distribution of welfare changes is expected to be similar for both the MCP scenarios, if the same budget is assumed, which does not seem possible in the near future. The welfare gains are predicted to be slightly larger (and more spread out) for the MCP-on-all-roads scenario in comparison to the MCP-on-freeways scenario. However, given the current costs, implementation costs for MCP-on-all-roads are more than the CBCP revenues. The predicted spatial distribution of welfare changes for a CBCP policy (with MCP on freeways) has implications for budget allocations. Eligible users in regions that are prominent losers (northwest and south DFW) could be considered for larger travel budgets. Alternatively, part of the CBCP revenue could be invested in those regions. The results suggest welfare gains to a majority of the users under a CBCP policy. An average DFW resident may gain more than that as predicted by the analysis if optimal congestion tolls are imposed. And various user types may benefit more or less (e.g., high VOTT vs. low VOTT travelers).

5.5 Conclusions

Joint DM models were estimated for different trip purposes and applied (with MSA feedback) to the DFW region to simulate different pricing scenarios. The short-term (employment locations held fixed) and long-term (employment locations flexible) traffic impacts for the MCP-on-freeways and MCP-on-all-roads scenarios were compared to the status quo (after four full feedback-with-MSA iterations). The 1999 DFW network links are divided into eight categories (e.g., freeways, HOV, and principal arterials). 14 percent of its lane miles are freeway,s and another 14 percent are principal arterials. The joint DM choice models suggest that travelers tend to prefer destinations and modes that have a lower generalized cost (travel time and cost). Thus, for an MCP scenario the travelers can be expected to avoid choices that involve (higher) tolls. In other words they might be expected to take the less-congested routes and/or choose destinations with lower generalized cost and/or shift from DA to other modes.

VMT for both the MCP scenarios was predicted to decrease by about 7 percent, indicating that people tend to choose closer destinations and shift (slightly) from DA to other modes. Freeway VMT decreased by more than 12 percent for both the MCP scenarios, suggesting that travelers shifted away from freeways because of the MCP tolls. When only freeways were priced, travelers were predicted to shift from freeways to principal arterials that acted as alternative routes. Flows on feeder links were predicted to decrease. The mode shifts were very marginal in favor of transit and walk-bike modes, indicating that travelers are more likely to change destination and/or routes rather than change modes. A 15 percent increase in transit ridership was predicted.

A comparison of VMT at different V/C levels suggested a reduction in congested travel for MCP scenarios. For MCP-on-freeways, VMT at V/C > 1.5 was predicted to all but disappear in the short run and fall by about 73 percent in the longer run. A corresponding increase in VMT at lower V/C levels was predicted, indicating a shift to relatively uncongested routes. The region's daily VHT was predicted to fall by about 6 percent for MCP-on-freeways and 10 percent for MCP-on-all-roads, in the short run. This was predicted to decrease further in the long run. A marginal increase in travel time-weighted speeds (total VMT divided by total VHT) was predicted for MCP scenarios in the short run, and this was predicted to increase further in the long run.

A holistic measure of these travel benefits is given by the change in consumer surplus. The analysis computed a spatial distribution of changes in consumer surplus across different user groups for the two MCP scenarios compared to status quo. Users near the CBDs were predicted to have the highest welfare gains. These net benefits are predicted to fall with increasing distance from the CBDs. Average travelers with budgets in all the CBDs and city centers (see Table E2.1 in Appendix E2) are expected to gain about $.40/day. Users in north DFW (excluding the Denton and McKinney CBDs), the northwest region (to the immediate west of Carrollton), and south DFW (between Cleburne and Waxahachie) are predicted to lose most, losing about $.30/day. Overall, a majority (about 95 percent) of the population with travel budgets experiences travel benefits from the CBCP policy as suggested by the welfare changes. These results reinforce CBCP's role as a welfare-enhancing congestion-mitigation tool.

The current analysis does not allow flexibility in departure period choice and assumes static assignment to the network. It also does not permit land use changes, which may occur, to some extent, following MCP implementation. Overall, the MCP scenarios suggested considerable congestion relief on the most congested facilities, but without significant mode shifts. The MCP scenarios, as expected in theory, seem to be successful in moderating congestion.

This chapter discussed the long-term and short-term traffic impacts and the welfare a CBCP policy. The long-term and short-term air-quality impacts of such a policy also need to be studied. The TDM application (and traffic assignment) gives the link flows and speeds as outputs. Emission rates of different pollutants and particulate matter were estimated as a function of speed using MOBILE6. These, in combination with link flow and speed information were used to develop mobile emissions estimates for DA and SR trips for status quo and the two MCP scenarios. The next chapter discusses the estimation procedure and the mobile emissions estimates.

6. Emissions Estimation

6.1 Introduction

Changes in travel patterns also affect the mobile emissions and hence the region's air quality. This chapter evaluates the air-quality impacts of a potential CBCP policy in the DFW region. The Environmental Protection Agency (EPA) uses six pollutants as indicators of air quality. It has established threshold concentrations for carbon monoxide (CO), lead, nitrogen dioxide, particulate matter (PM2.5 and PM10), ozone, and sulfur oxides, above which adverse effects on human health may occur. These are known as the National Ambient Air Quality Standards (NAAQS), and regions not meeting these standards are designated as non-attainment areas. The sources of the pollutants are classified as stationary sources, area sources, on-road mobile sources, and non-road mobile sources. Among these, CO, PM, and ozone are highly related to mobile sources (both on-road and off-road/non-road). Hydrocarbons (HC) and oxides of nitrogen (NO_x) are also present in vehicle emissions, and in the presence of sunlight these form ozone; hence, they are called precursor pollutants. Dallas–Fort Worth (DFW) is a serious non-attainment zone for ozone, requiring careful planning and thoughtful consideration of various potential transportation control measures. This study explores the air-quality impacts of marginal cost pricing (MCP) in the DFW region, in terms of on-road emissions.

The travel demand model (TDM) application results predicted an increase in average speeds on all 5 roadway types under both MCP scenarios. Vehicle miles traveled (VMT) and vehicle hours traveled decreased for MCP scenarios. Thus, MCP (and hence CBCP) is expected to have a positive impact on mobile source emissions and regional air quality. This chapter estimates such emissions from drive-alone (DA) and shared-ride (SR) trips under all 3 scenarios (status quo, MCP-on-freeways, and MCP-on-all-roads) in the short run and the long run. Emissions from trucks, buses, and DART trains are not considered in the analysis. Pollutant and particulate matter (PM2.5 and PM10) estimates are obtained using the EPA's Mobile Source Emission Factor Model, MOBILE6. This chapter provides a summary of the key results and scenario comparisons. The adopted methodology, MOBILE6 input parameters, speed-emissions relationship for different pollutants, and limitations are discussed in detail in Appendix F.

6.2 Emission Rates

Link-based emissions estimates were computed for the following pollutants (all gaseous) for the three policy scenarios:

1. Hydrocarbons, HC
2. Carbon monoxide, CO
3. Oxides of nitrogen, NO_X
4. Carbon dioxide, CO_2

These include exhaust running emissions, exhaust engine start emissions, evaporative hot soak emissions, evaporative diurnal emissions, evaporative resting loss emissions, evaporative running loss emissions, evaporative crankcase emissions, and evaporative refueling emissions. The emission rates at various speeds for hydrocarbons, carbon monoxide, and oxides of nitrogen, obtained from Mobile 6, are given in Figures F.2, F.3, and F.4 in Appendix F, respectively. The amount of carbon dioxide emitted was constant at 369 grams per VMT at all speeds.

In addition, particulate matter estimates were also computed. MOBILE6 has the option of restricting the particulate matter estimates to user-specified particle size cutoff values (PSCs). The user can specify PSC of 1 micrometer to get PM1. Link wise estimates of each of the following types of PM with PSCs of 2.5 and 10 (i.e. PM2.5 and PM10) were computed for the three scenarios:

1. Sulfate portion of exhaust particulate
2. Total carbon portion of gasoline exhaust particulate
3. Sulfur dioxide (gaseous)
4. Ammonia (gaseous)
5. Brake wear particulate
6. Tire wear particulate

The emission rates of PM2.5 and PM10 for the sulfate portion of exhaust particulate and sulfur dioxide are the same (see Figures F.5 and F.7 in Appendix F). Figure F.6 in Appendix F gives the emission rates of PM2.5 and PM10 for the total carbon portion of gasoline exhaust particulate at different vehicle speeds.

According to MOBILE6 estimates, emission rates for the rest of the particulate do not vary with speed (see Table F.1 in Appendix F).

Emission estimates for the above specified pollutants and particulate matter were computed for each link. Aggregating these over grids (as in Figure F.1 of Appendix F) would give a spatial distribution of emission estimates over the entire network. However, since the objective of the analysis is total daily estimates, the link-based estimates were aggregated over all links and times of the day. Most particulate matter (PM2.5 and PM10) estimates decreased in proportion to VMT for the MCP scenarios. The pollutant estimates also decreased for the MCP scenarios, but not quite in proportion to the VMT. Tables 6.1 and 6.2 give the absolute amounts (daily) and percentage change for all emissions in the MCP scenarios (relative to the status quo levels) in the short run and long run. The assumptions made in this analysis are discussed in the following section. The limitations are also mentioned.

Table 6.1 DFW daily (weekday) emission estimates (in tons) due to mobile sources in the short run

	Status Quo (tons)	MCP freeways (tons)	% change	MCP all roads (tons)	% change
Hydrocarbons	119.35	111.01	-6.99	111.26	-6.78
Carbon monoxide	1610.35	1512.37	-6.08	1537.17	-4.54
Oxides of nitrogen	118.05	110.35	-6.53	111.23	-5.78
Carbon dioxide	45893.05	42609.85	-7.15	43083.90	-6.12
PM2.5					
Sulfate portion of exhaust particulate	0.11	0.10	-5.39	0.10	-6.27
Total carbon particulate	0.48	0.45	-7.22	0.45	-6.12
Sulfur dioxide	2.6	2.41	-7.17	2.44	-6.12
Ammonia	12.64	11.73	-7.15	11.86	-6.12
Brake wear particulate	0.66	0.61	-7.15	0.62	-6.12
Tire wear particulate	0.25	0.23	-7.15	0.23	-6.12
PM10					
Sulfate portion of exhaust particulate	0.11	0.10	-5.39	0.10	-6.27
Total carbon particulate	0.52	0.48	-7.15	0.49	-6.12
Sulfur dioxide	2.6	2.41	-7.17	2.44	-6.12
Ammonia	12.64	11.73	-7.15	11.86	-6.12
Brake wear particulate	1.55	1.44	-7.15	1.46	-6.12
Tire wear particulate	0.99	0.92	-7.15	0.93	-6.12

Table 6.2 DFW daily (weekday) emission estimates (in tons) due to mobile sources in the long run

	Status Quo (tons)	MCP freeways (tons)	% change	MCP all roads (tons)	% change
Hydrocarbons	119.35	110.19	-7.67	109.03	-8.65
Carbon monoxide	1610.35	1524.01	-5.34	1516.18	-5.84
Oxides of nitrogen	118.05	110.21	-6.65	109.30	-7.41
Carbon dioxide	45893.05	42666.47	-7.03	42312.19	-7.80
PM2.5					
Sulfate portion of exhaust particulate	0.11	0.10	-7.06	0.10	-8.16
Total carbon particulate	0.48	0.45	-7.03	0.45	-7.80
Sulfur dioxide	2.60	2.41	-7.03	2.39	-7.80
Ammonia	12.64	11.75	-7.03	11.65	-7.80
Brake wear particulate	0.66	0.61	-7.03	0.61	-7.80
Tire wear particulate	0.25	0.23	-7.03	0.23	-7.80
PM10					
Sulfate portion of exhaust particulate	0.11	0.10	-7.06	0.10	-8.16
Total carbon particulate	0.52	0.49	-7.03	0.48	-7.80
Sulfur dioxide	2.60	2.41	-7.03	2.39	-7.80
Ammonia	12.64	11.75	-7.03	11.65	-7.80
Brake wear particulate	1.55	1.45	-7.03	1.43	-7.80
Tire wear particulate	0.99	0.93	-7.03	0.92	-7.80

6.3 Conclusions

Status quo and MCP scenarios were simulated for the DFW region, resulting in estimates of link flows and travel times. Travel times and link lengths produced speed estimates for use in MOBILE6, which estimated mobile emissions rates for personal vehicle (DA and SR) trips for each of the three policy scenarios. The various inputs for MOBILE6 include vehicle speed, fuel characteristics, temperature, vehicle age, and soak-time distributions, among others. Values specific to DFW were used for fuel RVP (6.8 psi), maximum/minimum (96/77 F) temperature. MOBILE6 default values and distributions were used for other fields.

Emission rates as a function of vehicle speed were computed for four pollutants (HC, CO, NO_x, and CO_2) and particulate matter (PM2.5 and PM10). The particulate matter included sulfates, carbon, sulfur dioxide, ammonia, brake wear, and tire wear. This, in combination with link-specific speed and flow information was used to compute total daily estimates by emission type for the three scenarios. The emissions estimates fell by about 7 percent for the MCP-on-freeways scenario and by about 8 percent for MCP-on-all-roads scenario in the long run. The PM estimates fell by the same amount as the VMT (as discussed in Chapter 5: 7 percent for MCP-on-freeways and 8 percent for MCP-on-all-roads, in the longer term). Although emissions above speeds above 65 mph were assumed to be the same as that at 65 mph, stable emission rates at high speeds suggest this to be a reasonable approximation.

As discussed in this chapter, CBCP is expected to reduce emissions. So, air-quality improvement, not just congestion mitigation, is a valuable benefit of CBCP, especially for DFW, which has been designated non-attainment status for ozone. The air quality benefits are difficult to quantify in monetary terms and are not included in Chapter 5's welfare estimates or in the coming chapter on implementation costs and CBCP revenues. But they are real. The results of our stakeholder interviews (Chapter 2) suggest that this is a real concern for businesses.

Based on the prediction of system-wide impacts and expert and public opinion, the CBCP policy was refined and recommendations for its implementation were developed. In addition, a thorough review of implementation costs was carried out. Toll revenues were estimated and typical CBCP travel budgets were computed. These are discussed in the next chapter.

7. Recommendations for Implementation

7.1 Introduction

Implementation of any significant transportation policy requires an understanding of the policy's system impacts, including related costs and benefits and likely stakeholder opinion. Such information allows the policy to be refined while providing direction for implementation. This project focused on gathering and analyzing this information to inform traffic congestion policy development. Based on the results of the qualitative and quantitative analyses, this chapter presents a set of guidelines for a CBCP application.

The guidelines address issues pertaining to practical trade-offs in budget allocation, enforcement, and administration. The following sections discuss in detail the policy recommendations resulting from this project, including estimates of implementation costs and toll revenues. In addition, tolls for typical commute trips are computed and monthly travel budgets are predicted based on net revenues.

7.2 Recommended Policy

A CBCP policy provides all eligible travelers a travel budget to spend on congestion tolls, via a transponder account linked to his/her name or vehicle (eligibility is discussed in the travel budget eligibility section below). Ideally, marginal cost pricing for delays induced by added road users would be imposed on all major, congested roads, and the net revenues would provide for these monthly travel budgets. Without system-wide roadway pricing, the optimal tolls will not reflect true, marginal delay costs since many non-priced (yet congested) routes are still available between origins and destinations. For maximally "efficient"[16] system operation, all complementary and substitute routes must be appropriately priced. Any budget not spent by the end of the month's time may or may not, depending on the chosen policy, serve as a cash savings or credit to the account holder. Those exceeding their budgets have to pay for any additional tolls out of pocket. Kalmanje and Kockelman (2004) provide estimates of total revenues and average travel budgets for a CBCP implementation in Austin. As originally conceived, the policy was meant to be revenue-neutral in that all revenues collected each month are distributed among all qualifying travelers in the region, after covering system administrative costs. In practice, actual, chosen policies may differ (e.g., revenue neutrality may or may not be adopted). Returning cash to participants is an incentive for fraudulent activity (via, e.g., ineligible persons claiming eligibility) that can be difficult and costly to regulate. In light of expert caution and concern regarding the administrative burdens of the policy, as originally conceived, several changes were made in constructing final policy recommendations, as described here.

7.2.1 Toll Tags

It is recommended that all system users be able to obtain a transponder for their vehicle(s) upon paying a refundable deposit. Users of IH 15's FasTrak lanes (in San Diego) and users of Dallas–Fort Worth (DFW) toll roads presently pay a refundable deposit of $40.00 in order to obtain a transponder. However, if low-cost tags are used (e.g., the eGo™ 2201 [Transcore 2002] costs

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[16] Markets are *efficient* when consumers absorb the marginal costs of their consumption, and are able to freely choose, in the presence of perfect information.

less than $10.00 per tag), then the users could be asked to buy their own tags. The transponders will be associated with unique, vehicle-specific accounts (an individual cannot have more than one account), which would have the following user data:

- User name
- Vehicle license plate number and/or a unique ID number
- User address (available from vehicle registration records)
- Credit card information (optional, but required if user chooses to pay tolls using his/her credit card)

Because travel credits/budgets are involved, CBCP involves more personal data collection than a CP application. Additional information could be maintained based on the methodology adopted to identify people eligible for a travel budget. For example, if budgets are to vary as a function of corridor use, such data could be kept. In addition, budgets may only be granted when sufficient identifying information is presented, such as documents showing an individual's vehicle to be insured and registered in the region of CBCP application.

7.2.2 Travel Budget Eligibility

One of the most difficult decisions and implementation issues associated with a CBCP policy is that of budget eligibility—and distribution. The two most likely criteria for eligibility are based on use of priced roadways and on location of residence. Both approaches have strengths and limitations—as well as several variations. A user-based criterion (e.g., based on a minimum number of miles or days driven) seems most relevant in a region where relatively few roadways are priced, so that those who really need the corridor are identified through use. A residence-based criterion works best when a well-defined region's network is extensively priced; and residents of different locations may be eligible for different levels of travel budget, depending on expectation of need and/or contribution to the network's provision (via property taxes, for example).

Different budget eligibility criteria and their associated limitations were considered in this project, such as allocating budgets only to registered vehicle owners versus all licensed drivers in a region. The potential for fraudulent representation of use and/or residence is what lead to the strategy recommended here: travel budgets are best tied to a vehicle (based on its use or its registration address), rather than to an individual's transponder (which can be shared easily with others). Drivers' own transponders also can be read, in addition to vehicle identification tags, but that would require additional investment in technology. So the final recommendation is to associate transponders with vehicles. Only licensed vehicle owners (whose vehicles are properly registered) would be eligible for travel budgets. Individuals also could be asked to share their insurance records in order to become eligible for a travel budget, thus reducing incidence on uninsured motorists.

Those owning more than one vehicle would be eligible to receive only one set of travel credits. Of course, persons could still register their vehicles under the names of licensed family members and others, and people might hold on to older and more polluting vehicles for such purpose. However, vehicle licensing, registration, insurance, inspection and maintenance costs are likely to substantially exceed base travel budgets, in most regions, particularly in regions where revenues are largely reserved for use toward transportation system expansion and enhancement. Thus, it is unlikely that many persons would hold onto extra vehicles (and retitle and reregister them) for the purpose of obtaining extra travel credits. Moreover, if older vehicles with poorly performing emissions systems were to become a pollution problem, roadside emissions inspection devices—coupled with toll tag readers—could quickly identify such vehicles and reduce or cancel budgets in order to compel compliance with emissions standards. Such technologies are complementary to CBCP and standard tolling. Other policy opportunities (such as speed limit enforcement) also may arise via extensive use of toll tags and roadside readers.

7.2.3 Treatment of Visitors

Toll technology experts indicated that enforcement is usually not easy if both ETC users and non-users use the same corridor. This could very well happen in a CBCP scenario since visitors (drivers) to the system may not have readable transponders. One option is to let visitors drive for free. This would require the system to keep track of such vehicles (via ANPR) so that fines are not pursued. Ideally, visitors would be required to purchase a day pass to use the priced corridors. In Melbourne, Australia's CityLink program has a similar daily pass option for its users (CityLink, 2004). Visitors would be asked for their vehicle license plate information on purchase of a day pass (which could be bought online or at a roadside store, as in London's cordon toll application). Vehicles without transponders that use the priced corridors would be detected by ANPR and vehicles tied to a purchased day pass would be removed from the violator list at day's end.

7.2.4 Budget Distribution

In general, the same budget level may be granted to everyone. However, if equity is a key consideration, multiple budget levels may be useful. Budget level could be based on employment status and household income. People with special needs could apply for a higher budget. If budget eligibility is determined by location of residence, then different packages/discount programs could be designed for people residing outside the CBCP budget eligible zone. For example, users of SR91 express lanes in California can opt for one of the four available account types: 91Express Club, Standard plan, Convenience plan, and Special access.

It should also be noted that if every eligible person receives his/her monthly budget on the same day, choice behaviors could result in undesirable traffic patterns depending on time of the month. People might drive initially and then shift to transit as they run out of travel budget, creating a temporarily high demand for transit services and low demand for road space. To prevent such fluctuations, budget distribution should be staggered.

7.2.5 Record Management

Every user would have an online account (updated daily) to access all charges, credits, and other account information. Tolls and any fines would be charged to users' accounts and would be accessible (and contestable) online. If payment is not received within a certain grace period, the State police could issue a citation (as in the case of North Texas Tollway Authority's Tolltag users, in the DFW region). Use of prepaid accounts and automatic deposit options can ensure balances remain positive.

7.2.6 Credit Controls

As originally conceived, CBCP involves a monetary transaction (in the form of a travel budget that can be accumulated and used to purchase other goods) from the managing agency to all travelers, including those without vehicles. Such an approach provides a relatively strong incentive for fraud (where ineligible persons claim eligibility)—along with administrative burdens and significant enforcement costs. To avoid such issues credits can be linked to locally registered (and insured) vehicles, and individuals not be permitted to accumulate—or cash out—their travel budgets.

By not returning all revenues in the form of cashable credits, system managers can retain a portion of revenues for alternative uses. And, by keeping travel budgets low—relative to revenues—and tied only to registered and licensed vehicle owners, fraudulent representation of eligibility becomes less of an issue, and more revenues become available for alternative uses. Those uses most popular among experts surveyed are maintaining existing roads, adding capacity, and investing in alternate modes like transit. Of course, a region's stakeholders and policy makers can make their own determinations. In some regions, transit subsidies may be most desirable; in others, attention to infrastructure needs (i.e., bridge expansion and other bottleneck points) may be the focus of additional revenue.

Given the above recommendations and the impacts of MCP scenarios, it is of interest to estimate the travel budgets for an average DFW resident under a CBCP policy. The average tolls for both MCP scenarios are discussed in the next section. This is followed by a detailed discussion on the implementation costs and total revenues. Based on this information, approximate travel budgets are computed, along with daily toll costs for specific peak-hour commute trips.

7.3 Revenues and Costs

Estimates of initial investment and recurring costs are required to predict net revenues and potential travel budgets for those who qualify. To assume that all freeways would be priced is conservative, since not all freeways are congested. DFW has 594 centerline miles (USDOT, 2000c) (about 3700 lane miles) of freeways. TDM results for the status quo suggest that about 60 percent of these are "congested" (V/C > 0.75). The following analysis assumes that 70 percent of the DFW freeway network is priced, i.e, about 415 centerline miles and 2600 lane-miles.

The initial cost estimate is \$48.3 million (Table G.4 in Appendix G), amounting to approximately \$11.00 per DFW resident. Readers should note that transponders (representing 62 percent of the total costs) could very well be covered by user deposits/purchases. CBCP operating expenses per lane-mile are estimated at \$100,000 per year, or a total of \$260 million for the DFW region's freeway system annually.

The total cost per resident obtained by applying a capital recovery factor to the initial cost—at an interest rate of 6 percent over a period of 10 years, the lifetime of the ETC system—is about \$55 per year per resident. This seems like a reasonable investment in order to address freeway congestion, which costs an average DFW traveler \$440.00 per annum (Schrank and Lomax, 2003). These cost calculations appear to support the case for CBCP as a worthwhile congestion mitigation strategy in a region like DFW.

The daily total revenues from CBCP (MCP-on-freeways) in the short run are predicted to be around \$2.4 million. So, deducting the costs from this gives monthly net revenue of about \$30.6 million. Assuming, 2.1 million budgets are required (70 percent of the number of vehicles in the DFW region), each budget would be \$14.60 per month. If budgets were to be given to commuters only, assuming about 90 percent of the commuters to be eligible for a budget gives \$11.30 per month per commuter. The cost, revenue, and budget computations are discussed in greater detail in Appendix G. Appendix G also gives average link-tolls for different MCP scenarios and tolls for typical peak-hour commutes.

7.4 Conclusions

Kockelman and Kalmanje (2004) first explored public perceptions of their original CBCP policy proposal, then examined the policy's short-term traffic and land value impacts for Austin, Texas. This study folds in stakeholders' and experts' opinions and predictions of long-term system impacts to produce recommendations for an even more refined CBCP policy. Academicians and practitioners in the field of transport economics, policy makers, administrators, and commercial users provided valuable feedback on issues of travel budget allocation, equity, efficiency, land use change, economic impacts, and alternative revenue uses. Toll technology experts provided recommendations for ETC technology (RFID and ANPR), system configuration, dynamic pricing issues, and variable message signs.

The revised CBCP policy proposal and associated implementation strategies aim to address stakeholders' and experts' concerns relating to the original policy proposal, including ease of implementation and use of revenues. Instead of offering cash credits to all licensed drivers in a "region," travel credits only for registered vehicle owners are proposed. Political atmosphere and financial constraints may govern if cash out will actually be allowed. Travelers with special needs can apply for additional travel credits, and net revenues can be reinvested in the transportation system. Options for issues like budget eligibility, system visitors, enforcement, and toll collection methods are suggested. The study concludes that RFID tags and ANPR may be most appropriate implementable technology. The study estimated average tolls and tolls for typical commute trips in different pricing scenarios. The study developed conservative estimates for both initial and recurring costs of implementing such a policy along DFW freeways; these are estimated to be about \$60 per resident when annualized. It also estimated monthly net revenues of \$30.6 million in the short run, which when allocated equally to "eligible" individuals (with roughly 70 percent of the vehicle population's owners designated as eligible) turns out to be around \$15.00 per person. This, however, in the long run is estimated to be closer to \$6 per person. The simulation results suggest CBCP to be a viable option for congestion alleviation on freeways. The main challenge is to garner public and political support for the policy. Hence, CBCP can be a valid option for cities looking for a viable strategy to implement CP.

8. Technology Evaluation and Review

8.1 Introduction

The past several years have witnessed tremendous impetus for deploying congestion pricing (CP) schemes in different countries worldwide. The recent interest in CP schemes is due to the advances in CP technology (Spasovic et al. 1994). There have been considerable methodological advances in CP modeling (see, e.g., Verheof 2002, Hearn and Ramana 1998, and Yang and Zhang, 2002); however, there may be significant differences among practical applications. A recent thrust lies in determining the applicability of different pricing schemes and the potential hurdles that arise in planning such applications. There were three projects in California that were intended to demonstrate the benefits of CP. The Bay Bridge Project involved a differential peak/off-peak toll structure, but this was not pursued due to a lack of public support. The I-15 demonstration project near San Diego (1997) gave users the opportunity to move from regular lanes to less congested high-occupancy vehicle (HOV) lanes by paying a toll. The pricing of a privately financed toll road in 1995 on State Route 91 in Orange County, California, is the third such project in that state. The private operator used differential pricing schemes based on time of day and traffic levels. Tolls were collected via Automated Vehicle Identification (AVI) transponders. All vehicles with transponders and a prepaid account were eligible to use the lanes.

Other ongoing and future U.S. demonstration projects will provide valuable information on technology implementation issues and the benefits of CP. Washington State's Puget Sound region has developed a phased approach for studying a possible pilot implementation. The key features of the pilot project are (i) in-vehicle GPS-based billing, (ii) system-wide pricing, and (iii) an experimental versus controlled research design. This pilot study is proposed to end in the summer of 2005. Many other states such as Oregon, Florida, New Jersey, and Texas are currently testing real world applications of different CP schemes. Relevant information about these projects can be found on the DOT Web sites.

An unresolved question in most of the demonstration projects is the identification of appropriate (inexpensive, effective and interoperable) technology for different congestion schemes. The recently concluded demonstration projects in Europe (under the acronym PRoGReSS) provide reliable information about experiences from different technology implementations. This resulted in valuable information on operational, planning, and policy-related CP issues. Although the experiences from PRoGReSS demonstration projects are not transferable to the U.S., they provide important insights and implications. A review of the literature shows very little discussion about how one might evaluate technology for different CP schemes. There are many dimensions to consider for evaluating technologies based on their costs, potential impacts, and usefulness. The parameters for the evaluation process in this chapter are imputed from the technology experiences of these projects. As technology plays a pivotal role in CP implementation, a more detailed structure is needed to guide the evaluation of the demonstrations.

This chapter of the report is organized as follows. The following section gives an overview of the congestion pricing technology experiences in different countries. The key results from the technology evaluation model follow. This chapter does not address the details of the technology review and the proposed evaluation framework, as these are discussed in Appendices H1 and H3, respectively.

8.2 Synthesis of Congestion Pricing Technology Experiences

The technology used in CP is highly dependent on the scheme in place. Various CP schemes have been proposed in the past, depending on time of day and distance traveled. Gómez-Ibáñez and Small (1994) classify them in seven basic forms: (1) point pricing; (2) cordon pricing; (3) zone pricing; (4) parking charges; (5) charges for distance traveled; (6) charges for time spent in the area; and (7) charges for both time spent and distance traveled. Various countries have tested different technologies for implementing CP. In this section we report the experience from the PRoGReSS project. The experiences from other countries are presented in Appendix H2. This synthesis aims at augmenting the previous reviews with recent developments and field experiences.

PRoGReSS, which concluded in May 2004, was a demonstration project concerned with issues related to road pricing in eight different European cities. Information about these projects can be accessed at http://www.progress-project.org, from which the following information was obtained. The information presented here is mostly from technology experiences in the last year; older information about this project can be found in Porter et al. (2004).

(i) Bristol, England—The main element of PRoGReSS in Bristol was not in the full implementation of the road pricing as anticipated originally. The primary focus was on a three-month technology trial between July and December 2003. Road user charging equipment was tested on a range of vehicles, from cars to heavy goods vehicles (HGVs). The demonstration involved the testing of Mobile Positioning Satellite (MPS) equipment and was based on cordon pricing of two of the main access routes into the city center. The equipment consisted of on-board equipment (OBE) attached to the dashboard of the volunteer's vehicle, with a lead to the power source and an antenna on the roof of the vehicle.

Two technology trials were conducted in 1998 and 2000, which concluded that dedicated short-range communication (DSRC) works well as a technology. The recent GPS demonstration project in 2003 suggested that GPS does not (yet) work well and that many methodological and technical issues need to be resolved before it can be implemented on a larger scale. The main problem with the GPS systems was that they require a unit to be installed in all the cars, making them costly—both financially and operationally. Bristol has yet to take a final decision on the enforcement technology, but it seems most likely that it will be automatic number plate recognition (ANPR).

(ii) Copenhagen, Denmark—The primary motivation for implementing CP in this city was to study mode shift changes. The technology experience from Copenhagen is that GPS technology is necessary for distance-based pricing but may prove too costly for cordon pricing. The main problem identified with the GPS-based system is that all units have to be installed in the vehicles before the pricing scheme can be implemented. This is a costly exercise, and before such a system can be implemented on a larger scale, further work needs to be carried out relating to methodological, software-related, and technical issues. However, an alternative technology—from an economic and organizational perspective—is to implement ANPR or DSRC technologies, which have proven to be cheaper and easier to implement. A key enforcement issue from this experience is that installing a nationwide GPS system is almost impossible because of the need to continuously monitor whether it is working when the car is turned on. Another possibility is to have mobile and stationary checkpoints.

(iii) Edinburgh, Scotland—The experiences at this site conclude that both transponder and ANPR-based technologies would be the best solutions for the pricing schemes considered. Based on this, the dual cordon-pricing scheme was selected as the preferred option. This design favors the ANPR-based technology, which does not require in-vehicle equipment. From the transactions point of view, the license purchasing scheme seemed to have performed well. One of the key enforcement issues was that lane-straddling was a bigger problem with ANPR technologies. It was also found that the overall level of successful reads could be increased by including both overlapping fields of view, and both front- and rear-facing cameras.

(iv) Genoa, Italy—A cordon-pricing scheme was tested to protect the historical city center and downtown in Genoa. This scheme covered a total area of about 2.5 km^2. The pricing was dynamic, varying according to the time of day, day of week, user type and environmental conditions. The technology was based on a roadside single-lane video camera; no OBU was used in this scheme. One of the primary reasons for selection of this technology was that maintenance is cheap and easy. The ANPR technology is used; it memorizes license plate numbers for every time period and sends this information to the central processing center, where checks for exemptions are conducted. The charging is based on eligibility.

The main experience in Genoa was that state-of-the-art ANPR technology is quite good and affordable, but it has an intrinsic rate of non-recognition. This value was reported approximately at about 7 percent in the real operational environment. This could be overcome by integrating the ANPR technology with a transponder reader for frequent users. Enforcement was not observed to be a major issue in this case, as the technology was designed to manage violations to the limited traffic zone. Standard municipal software for enforcement is already available for this specific purpose.

(v) Gothenburg, Sweden—The demonstration project in Gothenburg employed GPS-based equipment. The technology experience indicated that GPS systems are not sufficiently developed to be implemented in full-scale applications. The GPS technology did not perform to the satisfaction and needs certain improvements. Another observation from the experience is that the OBU functionality should be minimized due to cost and operational considerations. Transactions considerations led to the recommendation that there is a need to minimize the amount of information communicated to and from the vehicle. Two issues with enforcement were learned from this experience. First, the control system for enforcement should be based on verification of performed payments and not on the OBU equipment functionality. Second, all the enforcement should reside outside the vehicle to increase the reliability of payment.

(vi) Helsinki, Finland—The motivation for Helsinki to participate in this project was *not* to carry out a demonstration, unlike the other cities, but rather to perform a modeling study with a number of different scenarios for road pricing. The emphasis was more on organizing a stated preference survey and stakeholder interviews in order to study the potential behavioral impacts. This was done to bring awareness of CP as a demand management tool to the “key” authorities. Two schemes were modeled as part of the process, both of which were based on cordon pricing with distinct fee collection policies: passage-based and distance-based. The former system is an electronic fee collection system based on DSRC and a vehicle carrying a transponder. The latter scheme required an advanced OBU system like a GPS and a communication system to the central unit.

Technology-related issues were not the focus of the demonstration project in Helsinki. The network impacts of the two CP schemes were studied: passage and distance-based. Since it is still unclear whether GPS technology will be completely feasible in the near future, it’s still unresolved as to what technology should be used for distance-based pricing. Enforcement issues were not considered explicitly in this process. It was concluded however, that enforcement would be realized fully using the ANPR technology.

(vii) Rome, Italy—The main objective of pricing in Rome was to reduce the number of vehicles accessing the Limited Traffic Zone (LTZ) and to promote the use of public transport. The technology experience from Rome was based on the DSRC technology in combination with the standard ANPR system, using OCR technology. One limitation of this technology is that the electronic gate system neglects to detect a high percentage (roughly 15 percent) of vehicles entering the zone. This limitation was overcome by verifying the images taken before confirming the violation or checking with the OBU. The enforcement significantly improved and showed a constant decrease of about 10 percent after the activation with the electronic technology. The enforcement problem was high in special events, when the system was enlarged in time and the information was not communicated to all the citizens. This problem should be resolved by adoption of small variable message signs or special lights, to directly inform the drivers before they pass the gates.

(viii) Trondheim, Norway—A new tolling technology called AutoPASS was introduced in 2001 to complement the existing technology. The AutoPASS is an open standard system that is supported by Norway and is being proposed as a basis for standardization in Europe. The common method of payment is by a card called t:kort for all the transport services. This same card can be used for automated charging. These tags, or OBUs, are deployed in most of the vehicles in the city. A charge is levied when the vehicles leave the pricing zone. The technology experience in Trondheim was very encouraging. After twelve years of operations, all the components of the pricing scheme have an operating time of 99.98 percent or more. The standardization of the electronic fee collection has been the main goal of this demonstration project and is considered an important step in that direction. The procedure used for enforcement is based on taking video pictures of the violating vehicles. This is registered manually by an operator; this procedure was not automated because of the high investments needed in building an automated system.

8.3 Technology Evaluation Technique

There are numerous technology alternatives for an organization wishing to pursue CP. Further, with the rapid strides in tiny technologies (Savran et al., 2002); it is likely that technology options only will improve. An organization wishing to explore a particular CP scheme will be faced with the task of choosing an appropriate technology, potentially based on the list of performance measures provided in this section. These measures were developed from the perspectives of both the implementing agency and system users.

The ELECTRE IV method was proposed as a more advanced option to overcome these limitations. Another method based on fuzzy set theory (Dubois and Prade 1980) can be used to account for uncertainty in the criteria. However, this requires a much greater effort and has not been found to fare better than the ELECTRE IV method (Roy and Hugonnard 1982). The ELECTRE IV method was used to rank suburban line extensions in the Paris Metro System, in the late 1970s. The final partial ranking was entirely compatible with the compromise achieved through the recognition of the different viewpoints of the various political and social groups. Due to its advantages and apparent success, the ELECTRE IV algorithm was used to evaluate CP technologies here. The main features of the ELECTRE IV algorithm are described in Appendix H3.

8.3.1 Key Results from evaluation algorithm

The ELECTRE IV algorithm was tested on a subset of technologies that are commonly used in CP demonstrations. The different technologies used for evaluation are:
(i) Manual Toll Booths (MTB), (ii) Automatic Number Plate Recognition (ANPR),, (iii) Dedicated Short-Range Communications (DSRC), (iv) Global Positioning Systems (GPS), (v) Infrared Communications (IR), and (vi) "smart" lost-cost Radio Frequency Identification (RFID)

The key results from the analysis are shown in Table 8.1.

Table 8.1 Final rankings of the CP technologies

Technology	Option	Rank
Manual Toll Booth	1	4
ANPR	2	2
DSRC	3	4
GPS	4	3
Infrared	5	3
RFID	6	1

The intermediate steps in the analysis are shown in Appendix H3. The final results show that given the different parameters considered in this work, RFID is the best CP technology and ANPR is ranked second. Additional analysis on the stability of the results is presented in Appendix H3.

8.4 Summary

This chapter of the report provides a synthesis of some of the experiences from recent Congestion Pricing (CP) demonstration projects and a formal procedure for evaluating the appropriateness of various technologies. One benefit of the synthesis is the development of more precise measures of performance to evaluate the potential technologies. Using a state-of-the-art evaluation algorithm, ELECTRE IV, one is able to overcome many of the traditional drawbacks of other evaluation approaches. The usefulness of the approach is demonstrated on a subset of technology, some of which were tested in the PRoGReSS demonstration projects. In the near term, radio frequency identification (RFID) is found to be the optimal choice, based on the analysis in this chapter. In the longer term, the research team believes that digital short-range communication (DSRC) technology should become a wise choice, as affordability increases.

9. Dynamic Traffic Assignment

9.1 Introduction

Joint destination-mode (DM) choice models for the Dallas–Fort Worth (DFW) region were estimated from the DFW 1996 household survey data for different trip purposes and applied with full feedback (using the method of successive averages) to the DFW region. Two marginal cost pricing (MCP) scenarios in addition to the status quo were simulated: MCP-on-freeways and MCP-on-all-roads (see Gulipalli 2005). As discussed in Chapter 5, the MCP-on-all-roads scenario has very high associated initial and recurring costs, and it is not practically feasible in the near future. Due to these facts and especially the excessive computational time of a dynamic traffic assignment (DTA) run for the large-scale DFW network, the MCP-on-all-roads scenario is not considered in this chapter. Rather, the focus is on the other two scenarios: status quo and MCP-on-freeways.

The travel demand model application for the status quo yields trip origin-destination (OD) information for five time periods and four modes. The static ODs for the three modes (drive-alone, shared-ride, and truck trips) in the five times of day were combined by first converting each truck trip to two passenger car equivalents (HCM 2000) and then summing up the drive-alone trips, shared-ride trips and converted truck trips for each OD and time of day. With these 24-hour static OD trips, the new proposed demand profiling method (described in Appendix I4) was used to generate the smoothed time-dependent OD trips. Only the demand during the AM peak (6:00 AM–9:00 AM) was used for this analysis.

This chapter involves the adaptation of the existing dynamic network modeling software VISTA (Ziliaskopoulos and Waller 2000) for the evaluation of network path flows over time, under the status quo and MCP-on-freeways scenarios. Appendix I1 provides a VISTA overview, while Appendix I2 shows the DTA solution algorithm. This chapter begins by discussing the VISTA code modifications required for this novel application, followed by discussions of the network's coding, assignment results, and modeling limitations.

9.2 VISTA Code Modification

Three major tasks required by this work involved VISTA's time-dependent shortest path (TDSP) algorithm, demand profiling for the static/constant inputs, and VISTA's incorporation of time-dependent marginal cost pricing (MCP).

The first modification was made in the TDSP algorithm, in order to account for tolls, under an assumption of homogeneous users (i.e., a single value of travel time [VOTT]). Ten dollars per vehicle-hour was used in order to be consistent with the static analysis described in Chapter 5. The $10/hour VOTT was used to convert tolls to a time penalty, characterized as additional time perceived by each driver. For example, a $0.33 toll charge is equivalent to two minutes of additional travel time. This added time or "delay" obviously does not impact the actual time spent within the network, but it is used within the TDSP algorithm. The modified algorithm is called the time-dependent least-cost path (TDLCP) algorithm, and it routes each vehicle such that it chooses a path with the least generalized cost (toll-based time penalty plus actual travel time). Appendix I3 provides the TDSP and TDLCP algorithms.

The second modification addresses an important issue in demand profiling. Since there is no time-varying OD demand data available, VISTA's default demand profiling method is a uniform (i.e., constant) rate of trip making over the specified simulation period. Of course, it is unrealistic to expect that travelers depart each origin uniformly over time, particularly since at the border of two time periods there will be severe jumps in demand rates. Thus, we propose a new demand profiling method that smoothes a series of static demands over 14,400 six-second time steps (comprising a 24-hour day). The result is that no discontinuous jumps are observed in demand at the border of any two time periods, and travelers no longer depart uniformly within each time period. The details of this proposed demand-smoothing algorithm appear in Appendix I4.

Finally, this DTA work did not attempt to solve for the truly optimal or marginal-cost dynamic pricing policy because it is a highly complex problem. Instead, an approximate method is used, employing each link's marginal congestion cost estimate to compute time-dependent tolls on freeways, updating these every five minutes. This heuristic method assumes that a vehicle entering a tolled link imposes marginal congestion costs only on vehicles that use the same link, rather than impacting travel times (and thus costs) on other links. The details of the heuristic for dynamic MCP are provided in Appendix I5. With these three major modifications, the DTA scheme has to be modified for the analyses of the status quo and the MCP-on-freeways as discussed in Appendix I6.

9.3 Network Assembly

As provided by North Central Texas Council of Governments (NCTCOG), the 1999 DFW roadway network has 26,748 lane-miles and 22,187 links. As discussed in Chapter 4, this was modeled using travel time-related behavioral feedbacks in TransCAD. In Chapter 5's static approach to network assignment, the DFW network has 13,694 nodes, 4,874 centroids, 22,187 links, and 9,805 centroid connectors. TransCAD's links and centroid connectors can be either unidirectional or bidirectional. Since VISTA has its own required data format, these TransCAD network data were converted into VISTA file formats. All links in the VISTA database must be unidirectional. Thus, the number of links used by VISTA is greater than that in TransCAD, but the number of nodes remains the same. A major concern in running DTA is the amount of memory consumed; especially in generating the competitive least-cost paths for every six-second time step and every OD pair. Since the number of zones (centroids) impacts these memory requirements directly, a relatively aggregate zonal system was used. In VISTA, the DFW roadway network still has 13,694 nodes, but just 919 centroids. It has 35,732 links, and 3,642 centroid connectors (or four connectors per centroid). The zonal structure is that previously used by NCTCOG. Specifically, four essential VISTA tables are Nodes, Links, Linkdetails and Demand, and their required formats are shown in Tables I1.1–I1.4, of Appendix I1.

9.4 Congestion Pricing Evaluation Results

The analysis focuses on the AM peak (6:00 AM–9:00 AM). An assignment interval is ten minutes, resulting in eighteen assignment intervals over three hours of simulation time. A simulation time step is six seconds, yielding 1800 time steps over three hours. A single VOTT of $10 per hour (per vehicle) was assumed. In order to build a set of competitive path choices for each time step and every OD pair, five DTA iterations were run, followed by the update-cost-DTA module, until achieving convergence for both scenarios (status quo and MCP-on-freeways). A comparison of the two scenarios' results is provided here. This is followed by a comparison of the static and dynamic results. In addition, freeway link flows and associated MCP tolls are explored.

9.5 Comparison of Traffic Impacts for the Status Quo and MCP-on-freeways from Static and Dynamic Traffic Assignment

This chapter's DTA results are compared both to one another (status quo vs. MCP-on-freeways scenarios) and to the static analysis with its full behavior feedbacks. Traffic impacts for the status quo and MCP-on-freeways scenarios are compared in terms of VMT, VHT, average speed, and number of affected vehicles, during the AM peak period. For the comparison with the static models, the DTA and STA traffic impacts are compared, in terms of VMT, VHT, and average speed. Please note that the short-term STA traffic impacts come from both the AM and PM peak periods, so they are not perfectly comparable to the three-hour AM peak period results found using DTA. However, the differences are so striking that this distinction is not of major consequence. All STA results are taken from Chapter 5 of this report.

9.5.1 System Level Comparison

Table 9.1 the predicted changes in system-level (i.e., total) VMT, VHT, and average speed during the AM peak when freeways are priced, versus status quo. The DTA results appear insignificant, both in isolation and when compared to the behavioral changes evident under the STA approach. The directions of changes for STA and DTA results are not in agreement for system VHT and average speed. The STA results are consistent with expectations. The DTA results are less so. Of course, the DTA models did not permit the behavioral feedbacks that the STA approach did, so the travelers were far more constrained and changes were fully expected to be much less dramatic.

Table 9.1 Traffic Impacts of MCP-on-Freeways, as Compared to the Status Quo

	DTA (AM Peak)	STA (Short-Term; Peak Period)
System VMT	Fall by <1%	Fall by 7%
System VHT	Rise by <1%	Fall by 6.39%
System Average Speed	Fall by <1%	Rise by 3.27%

9.5.2 VMT, VHT and Average Speed by Roadway Facility Types

Estimates of VMT, VHT, average speed, number of affected OD pairs, and number of affected vehicles, as categorized by different roadway facility types, are shown in Figures 9.1 through 9.5 for DTA applications. The internal comparison of the DTA results for status quo versus MCP-on-freeways is made as follows. The numbers of total vehicles and OD pairs whose travelers use freeways and ramps are predicted to fall very slightly when MCP tolls are imposed (i.e., by less than 1 percent). This means that fewer travelers select freeways and ramps in the presence of MCP tolls, as expected. Freeway and ramp VMTs for the MCP-on-freeways scenario are predicted to rise very slightly (again by less than 1 percent), while freeway and ramp VHTs are predicted to fall by 1.53 percent and <1 percent, respectively. Freeway and ramp average speeds for the MCP-on-freeways are predicted to rise by 1.89 percent and <1 percent. This may imply that more short-trip travelers using freeways in the status quo tend to choose non-freeway routes to avoid MCP tolls, while more long-trip travelers switch to stick with freeways, thanks to the travel time savings offsetting MCP tolls. Principal-arterial, minor-arterial and frontage-road VHTs for the MCP-on-freeways scenario are predicted to rise very slightly (by less than 1 percent), while their speeds are predicted to fall by <1 percent, <1 percent and 3.32 percent, respectively. This means the principal arterial, minor arterial, and frontage roads are predicted to become somewhat more congested when MCP tolls are applied on freeways because more short-trip travelers that use freeways in the status quo leave the freeways and those these facility types, when tolls are applied. Principal-arterial, minor-arterial, and frontage-road VMTs for the MCP-on-freeways are predicted to fall by <1 percent. This may imply that more longer-trip travelers that use arterials in the status quo are attracted to freeways in the MCP-on-freeways. All these results are expected to be amplified considerably when behavioral feedbacks for destination and mode choice shifts are permitted.

The VMT, VHT, and average speed by roadway types are shown in Figures 9.6–9.8, for both DTA and STA analyses. In the VISTA DTA model, minor-arterial VMT is predicted to be highest, followed by principal-arterial VMT, and freeway VMT (around 10 to 15 percent of total VMT). In dramatic contrast, under the STA model freeway VMT is predicted to be highest (around 50 to 60 percent of total VMT), followed by minor-arterial VMT and principal-arterial VMT. A similar trend is witnessed for VHT distribution across the network. Of course, the STA model is a 24-hour model, so freeways may attract more travel during the off-peak hours, but the contrast is still striking if one considers just the three-hour peak period for the STA analysis.

Predicted freeway speeds average between 55 and 65 mph, under the peak periods STA analysis, while under a DTA approach for the morning peak period, a speed of 30–35 mph is predicted. The range of estimated average speeds for all facility types under the STA approach is 25–65 mph, while that for DTA in the three-hour peak is just 15–35 mph. These indicate a drastic difference between STA and DTA results, and suggest very different behavioral assumptions regarding traffic performance. Interested readers may find information on the results of DTA approximation (different DTA scheme), which was not explored in this report, in Kockelman et al. (2006).

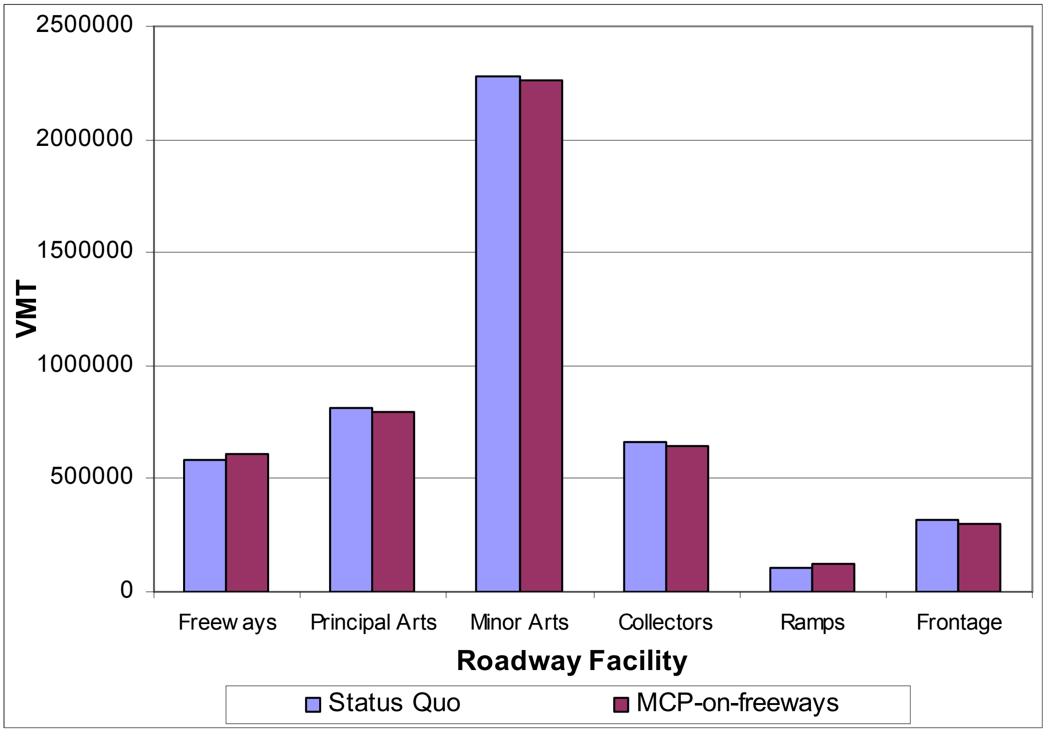


Figure 9.1 AM-Peak VMT by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA

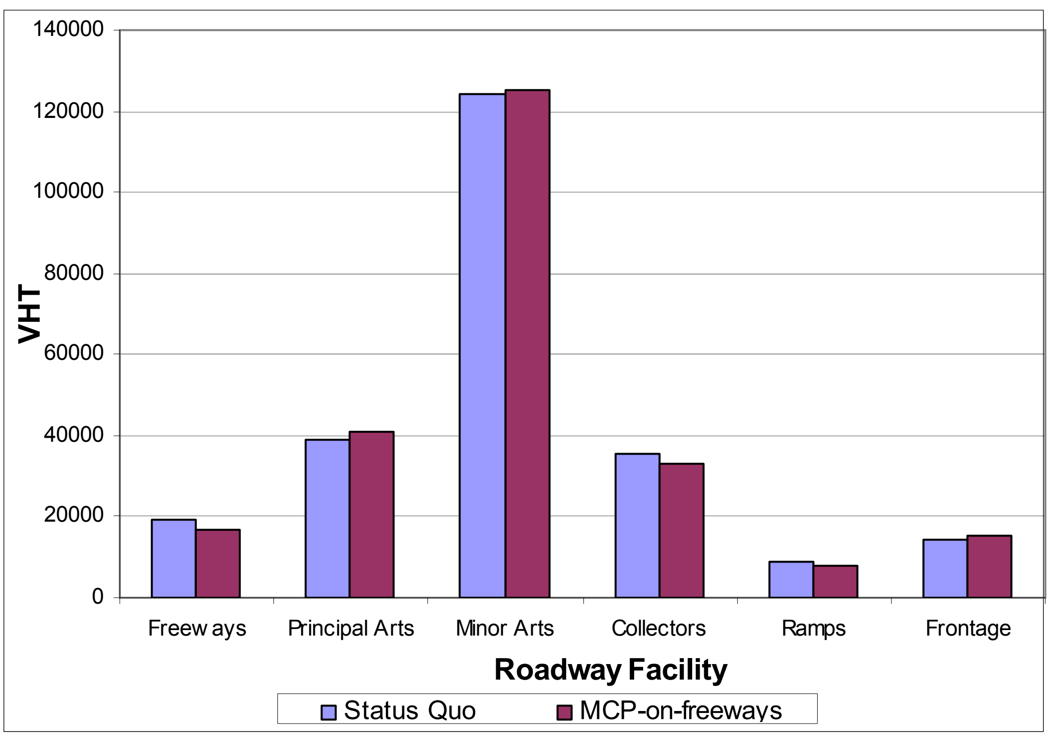


Figure 9.2 AM-Peak VHT by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA

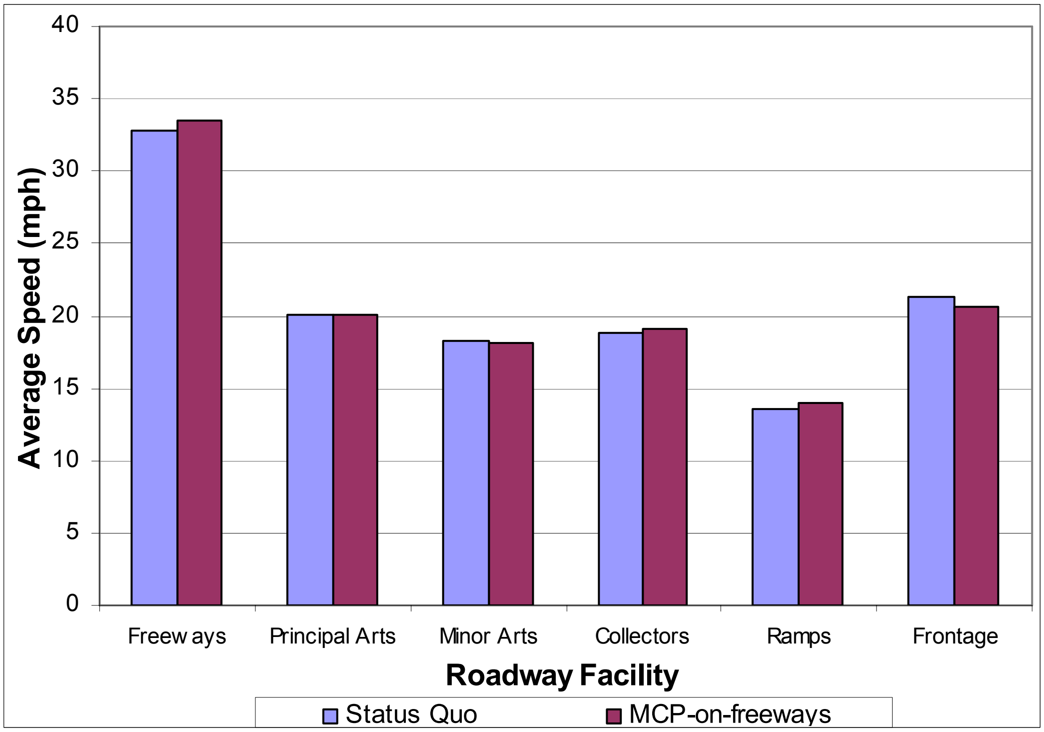


Figure 9.3 AM-Peak Average Speed by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA

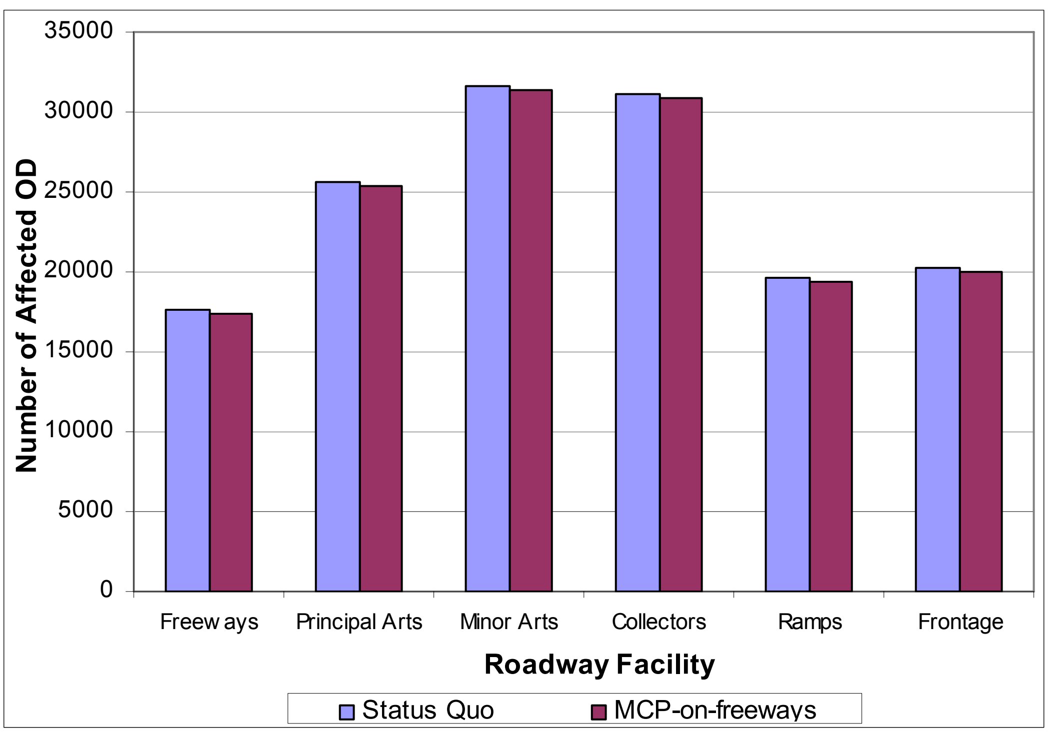


Figure 9.4 AM-Peak Number of Affected OD by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA

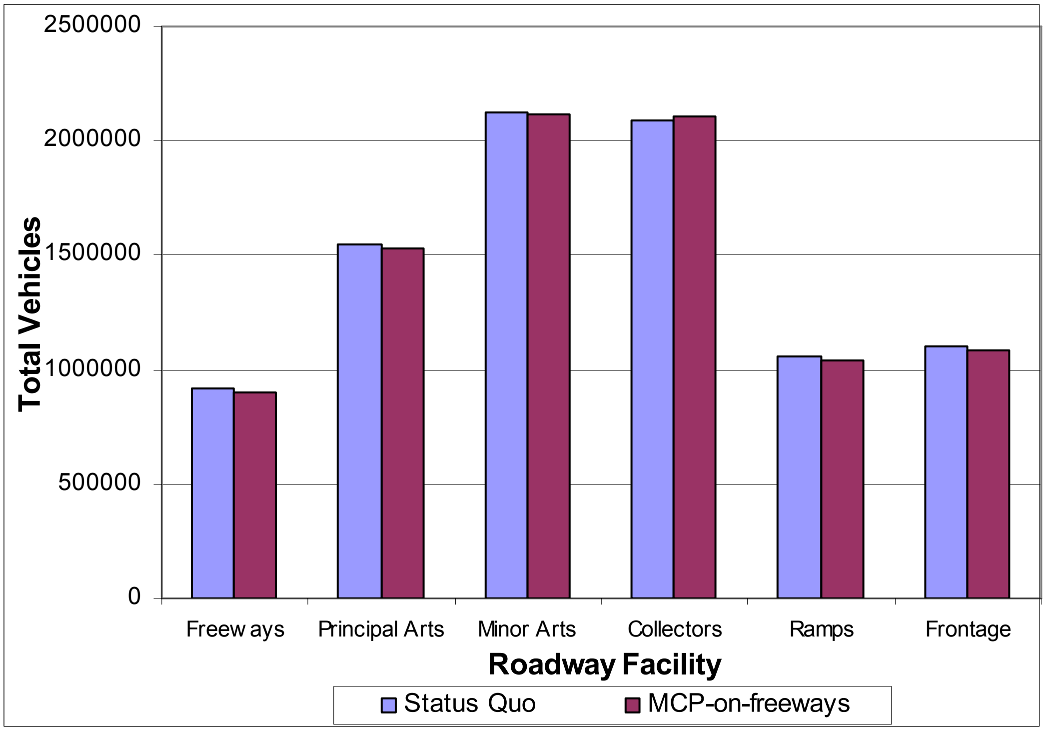


Figure 9.5 AM-Peak Total Vehicles by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA

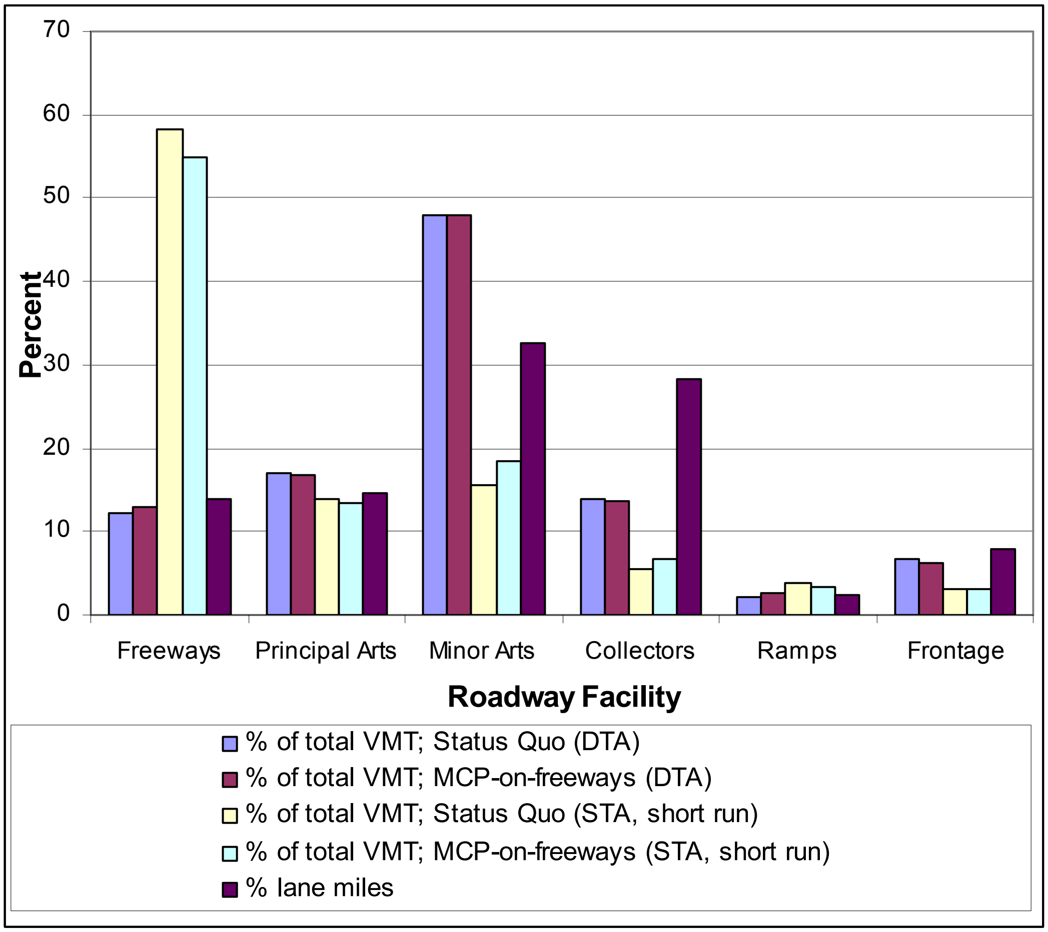


Figure 9.6 VMT by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA (AM Peak) and STA (AM + PM Peak Periods)

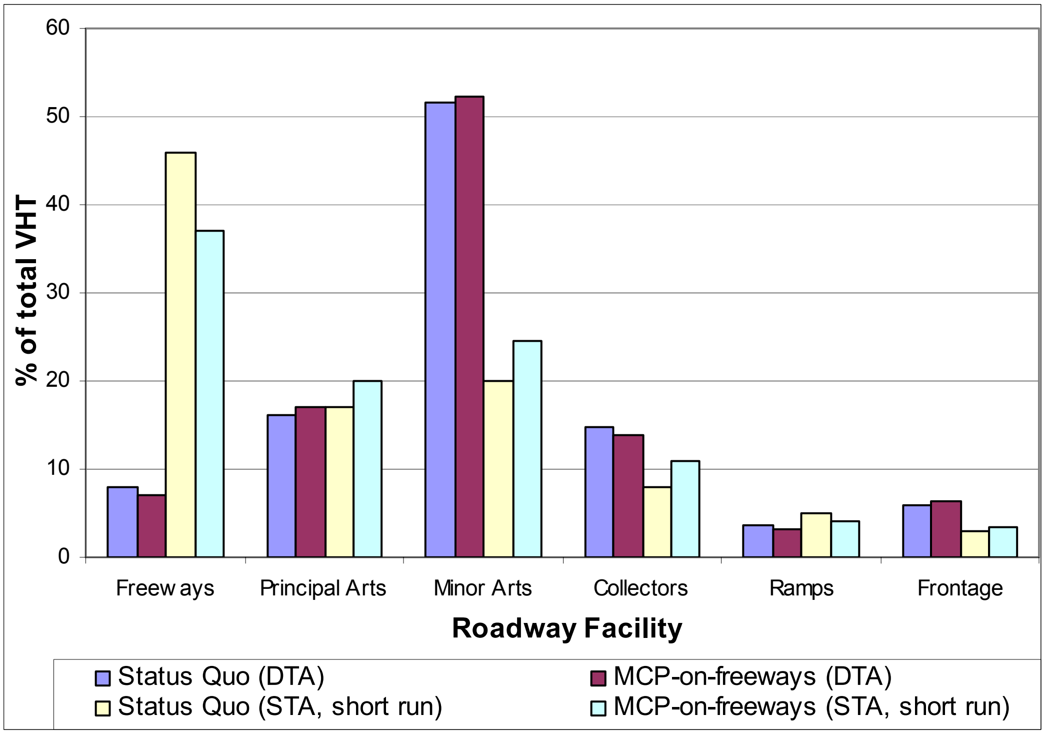


Figure 9.7 VHT by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA (AM Peak) and STA (AM + PM Peak Periods)

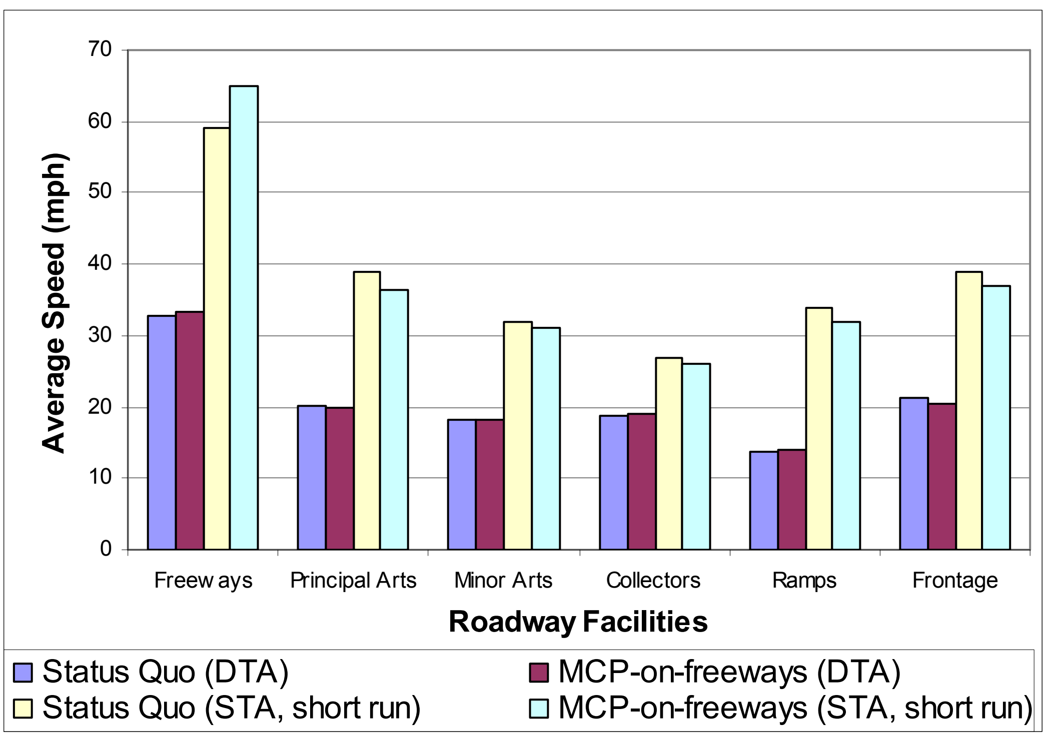


Figure 9.8 Average Speed by Roadway Facility Type for Status Quo and MCP-on-freeways from DTA (AM Peak) and STA (AM + PM Peak Periods)

VMT vs. Volume-to-Capacity Ratios

Although the volume-to-capacity ratios in a DTA approach is rather useless and certainly not comparable to what people are used to discussing due to prediction of true flows (rather than demand-to-capacity ratios), the VMT and volume-to-capacity ratios are examined here in order to be consistent with the analysis in Chapter 5. To appreciate the DTA-based traffic effects that MCP of freeways may have, VMT and VHT were split into five categories based on the following V/C levels: [0, 0.50], [0.50, 0.75], [0.75, 1.00], [1.00, 1.50], and [1.50, +infinity]. For V/C ratios between 0 and 0.5, freeway VMT for the MCP-on-freeways is predicted to rise by less than 1 percent, and freeway VHT for the MCP-on-freeways is predicted to fall by just 1.53 percent. This reiterates the previous observation that longer-trip travelers use more freeways, and freeways are less congested as a result of MCP tolls. As seen in Figures 9.9 and 9.10, freeway VMT at the lowest V/C interval (0–0.1) is predicted to rise by 1.35 percent, and freeway VHT in the same V/C interval is predicted to fall by <1 percent. This underscores the benefit of MCP-on-freeways, which appears to encourage longer-trip travelers to use the less congested freeways.

Travel at different congestion levels may be measured in terms of a VMT percentage at those different V/C ratio levels. Figure 9.11 shows the percentage of travel by V/C ratios from STA and DTA approaches. The percentage of travel from STA spreads out over all V/C ratios more than that from DTA. This again shows a significant difference between STA and DTA results. It is noted that the underlying calculations of volume-to-capacity ratios are different. In DTA, the traffic volumes are the true flows, whereas in STA, the volume is simply demand. Thus, these volume-to-capacity ratios may not be seen as totally comparable; however, it is shown in this section for completeness.

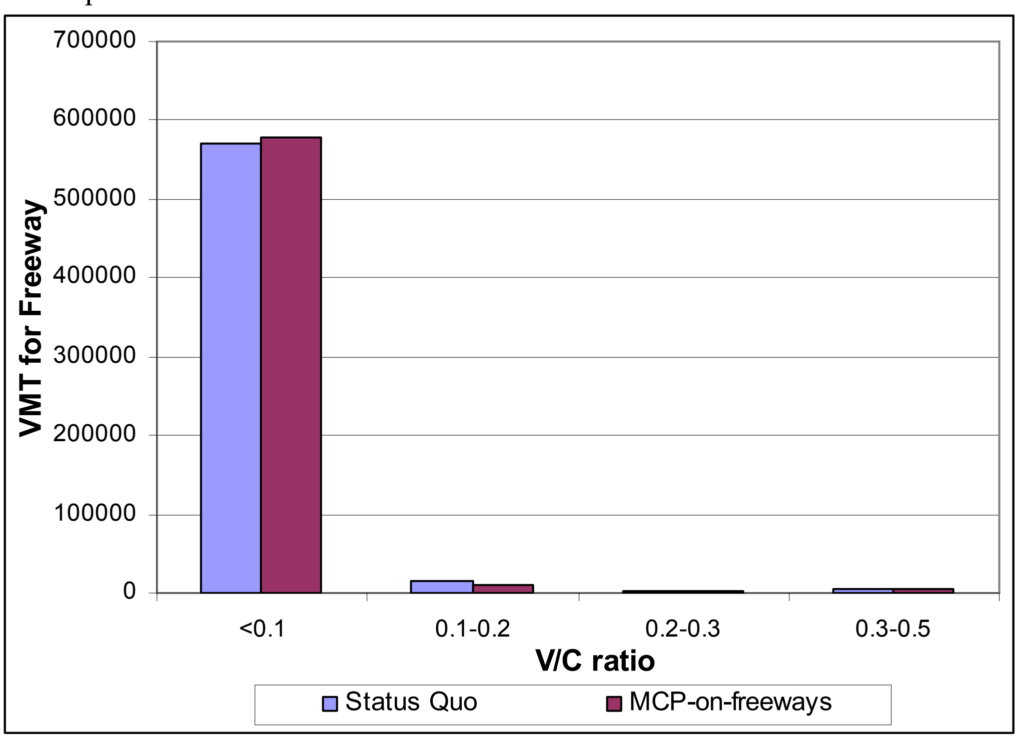


Figure 9.9 AM-Peak freeway VMT by Volume-to-Capacity Ratio for Status Quo and MCP-on-freeways from DTA

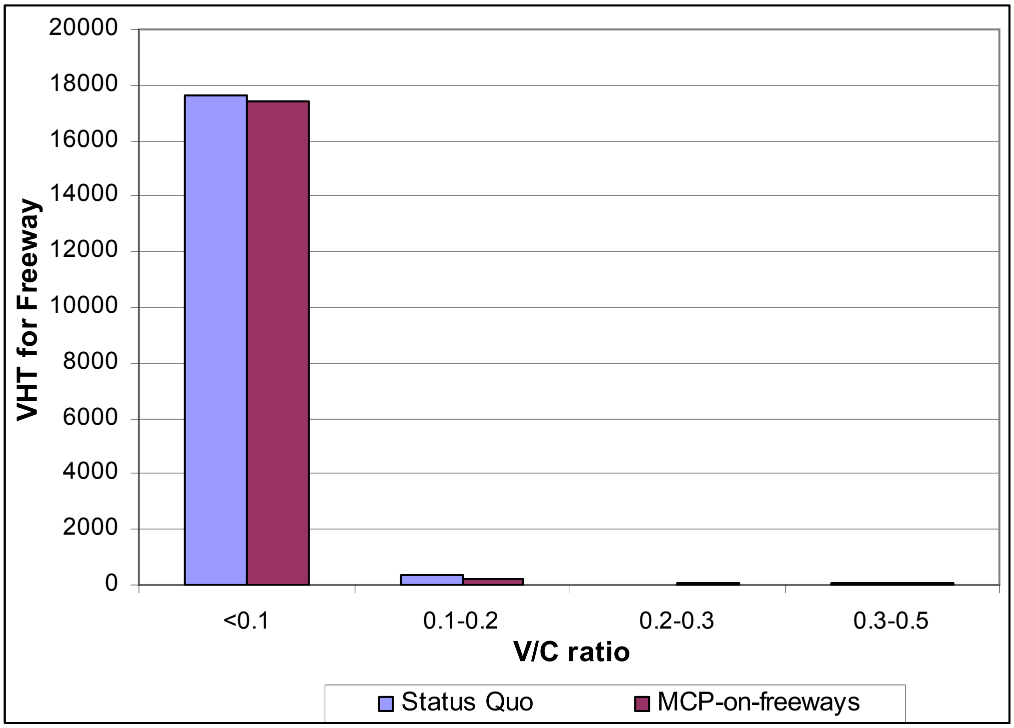


Figure 9.10   AM-Peak Freeway VHT by Volume-to-Capacity Ratio for Status Quo and MCP-on-freeways from DTA

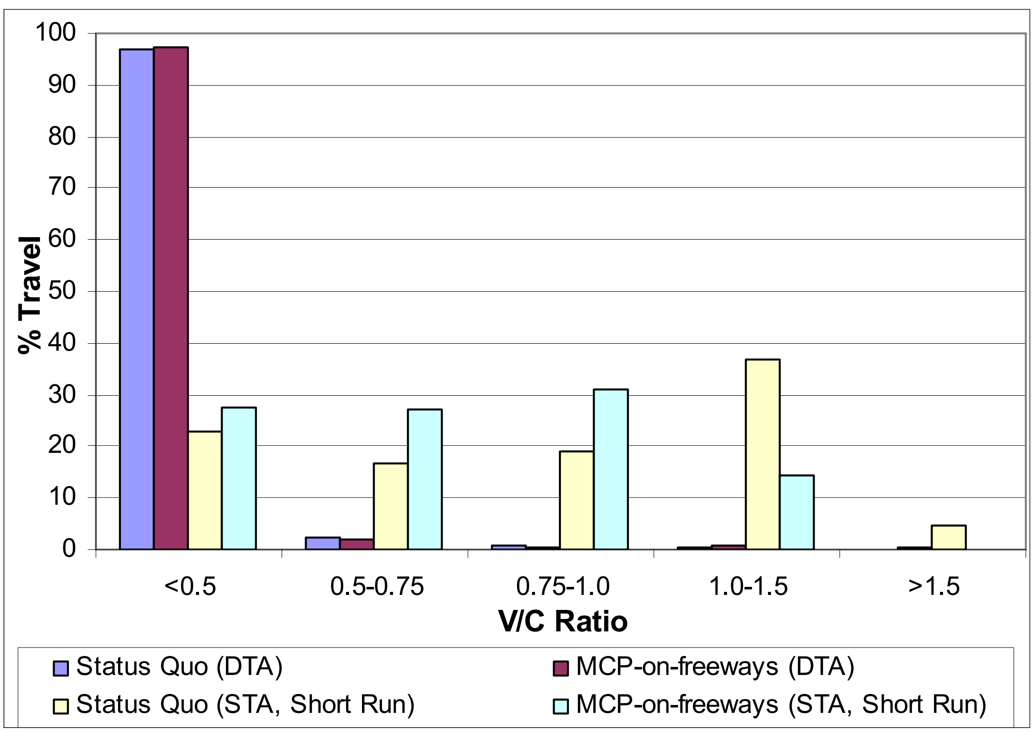


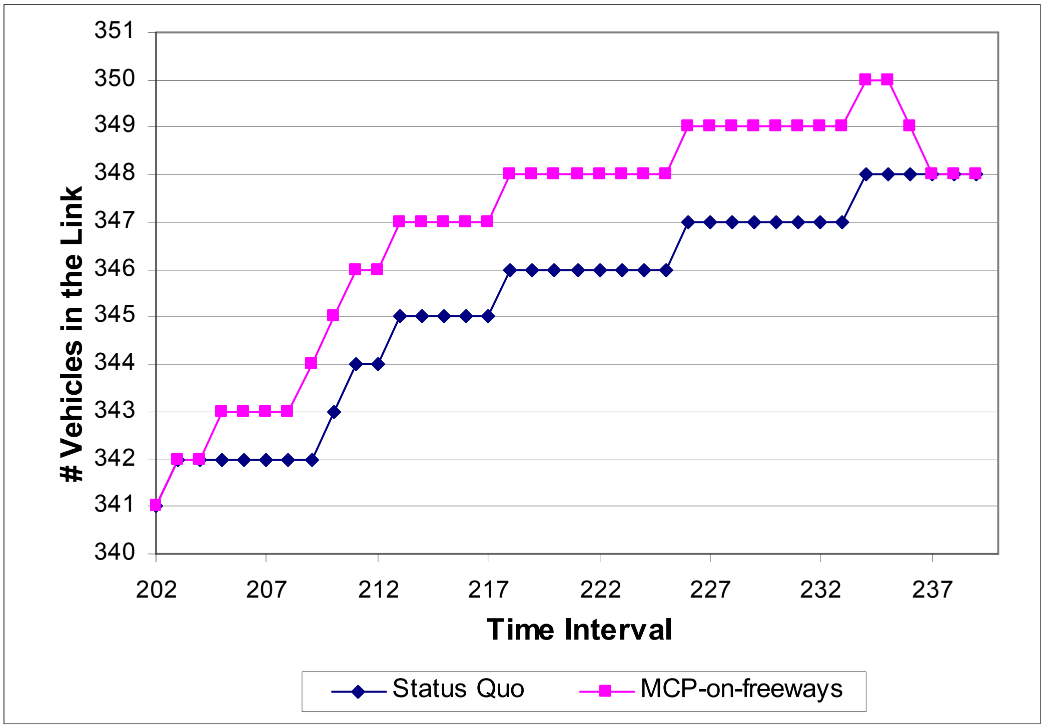
Figure 9.11   VMT Percentage of Travel by Volume-to-Capacity Ratio for Status Quo and MCP-on-freeways from DTA (AM Peak) and STA (AM + PM Peak Periods)

9.5.3 Possible Reasons of Considerable Difference between STA and DTA Results

As also discussed in the limitations section, provided at the end of this chapter, the drastic differences between DTA and STA results may stem from the following modeling distinctions. First and foremost, the static analysis allows feedback of travel time and cost information to destination and mode choices. The dynamic model is without feedback: travelers are only allowed to change route. Thus, travelers in the dynamic model are substantially more restricted, resulting in negligible estimates of VMT, VHT, and speed changes when MCP is applied. Also, the centroid structure employed in the DTA model is much more limited than in the STA case. It consists of 919 zones (or centroids) and 3,642 centroid connectors, while the STA model uses 4,874 zones and 9,805 centroid connectors. Thus, the DTA centroid structure cannot load and unload the network as uniformly or rapidly as the STA structure. This may result in more congestion around entry nodes in the DTA network. In addition, there is a difficulty in DTA peak period analysis: some travelers depart but cannot complete their trips by the end of the three-hour AM peak period analysis. The ideal analysis is a 24-hour period; however, this is effectively impossible at present, due to computer memory limitations. The three-hour study period (AM peak) may not be sufficient for "warming up" and "cooling down" the network; substantial traffic shoulders may exist, making congestion more severe at the start and end of the peak period. Note that in the beginning of DTA, the network is empty, so the warming-up period is employed to populate the network; then the true analysis period starts. In the same way, the cooling down period is employed after the analysis period to clear all vehicles from the network. All DTA results are determined only from the analysis period. In addition, the STA model's BPR parameters are arguably too low (and apply to "effective capacity," which is lower than the actual capacity used); this results in higher speed estimates. The effective capacity is essentially the maximum service flow under level of service C, rather than true capacity under level of service E. In contrast, the DTA model parameters may result in biases that overestimate the level and extent of spillbacks and congestion.

9.6 Exploration of Density on Freeway Links

Next, we explore the number of vehicles in four randomly selected links (i.e., their traffic density) over the analysis period, using DTA methods. Figure 9.12 shows the density of a freeway link that is 0.24 miles long and presently operates without tolls. The maximum MCP toll on this link is \$0.27 per mile. Figures 9.13–9.15 show the density of freeway links that presently operate without tolls. . In Figures 9.12–9.15 it can be seen that time shifts in traffic demands take place on all these freeways, as a result of MCP tolls. The MCP toll estimates under these DTA methods (as determined using the algorithm explained in Appendix I5), and these range from \$0.10–\$29.2 per mile on the region's freeway links. Obviously, anything over \$10 or \$20 per mile is probably unrealistic, at any time of day, even for very short sections (i.e., narrow bridge crossings). The DTA model seems to be overestimating MCP tolls. In STA, the toll rates went only as high as \$0.33 per mile.



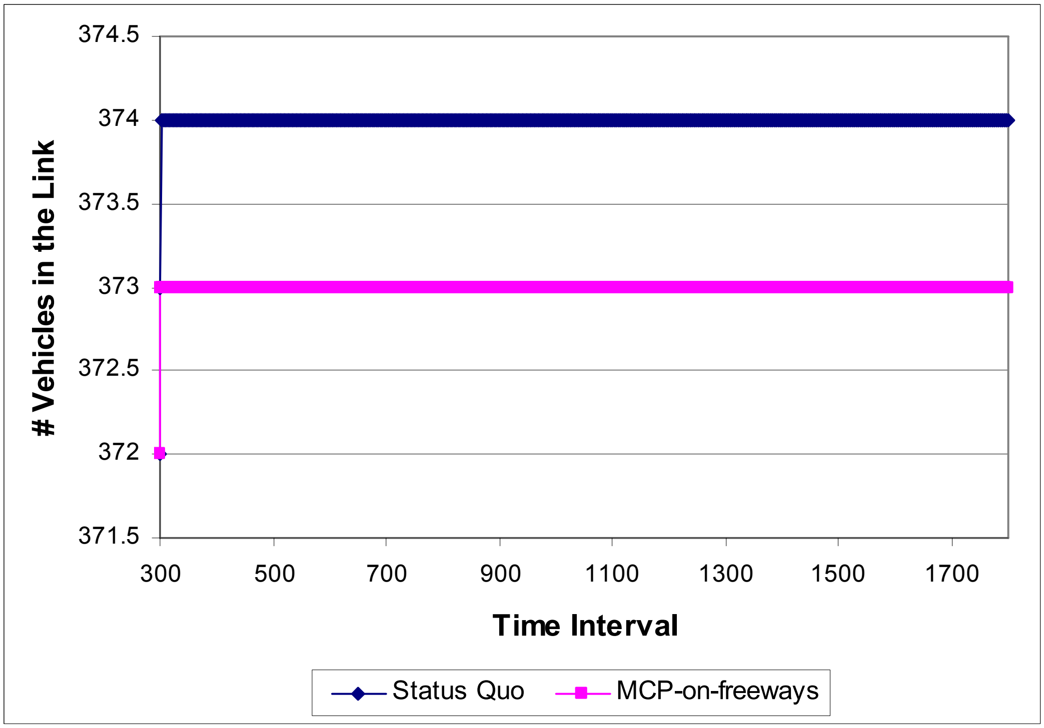


Figure 9.12 a & b: Time-Varying Traffic Flow of Freeway Link ID 20197

(SH114 NB, Between Macarthur and W SH114)
(Length = 1267.2 ft, MCP toll Rate Max = $0.27/mile)
(Total Vehicles = 626114 for Status Quo, 624675 for MCP-on-freeways, Capacity = 6450 vph)

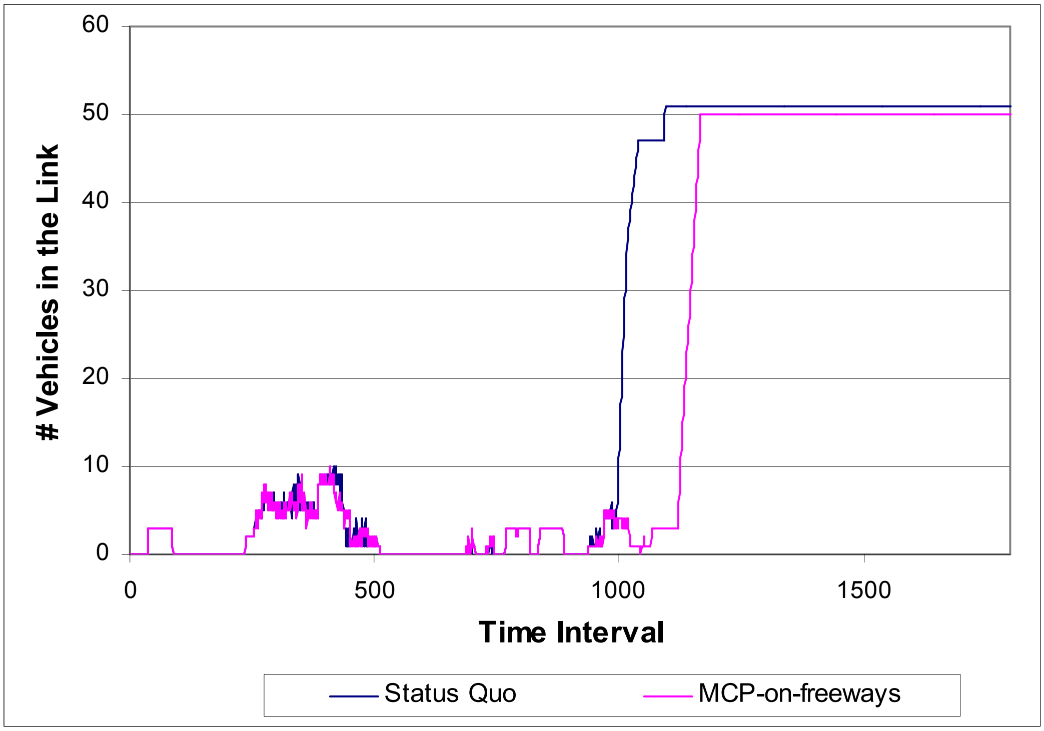


Figure 9.13 Time-Varying Traffic Flow of Freeway Link ID 12

(US287 SB, Near Wise CO LIN)
(Length = 3273.6 ft, MCP Toll Rate Max = \$0.39/mile)
(Total Vehicles = 41861 for Status Quo, 35109 for MCP-on-freeways, Capacity = 4600 vph)

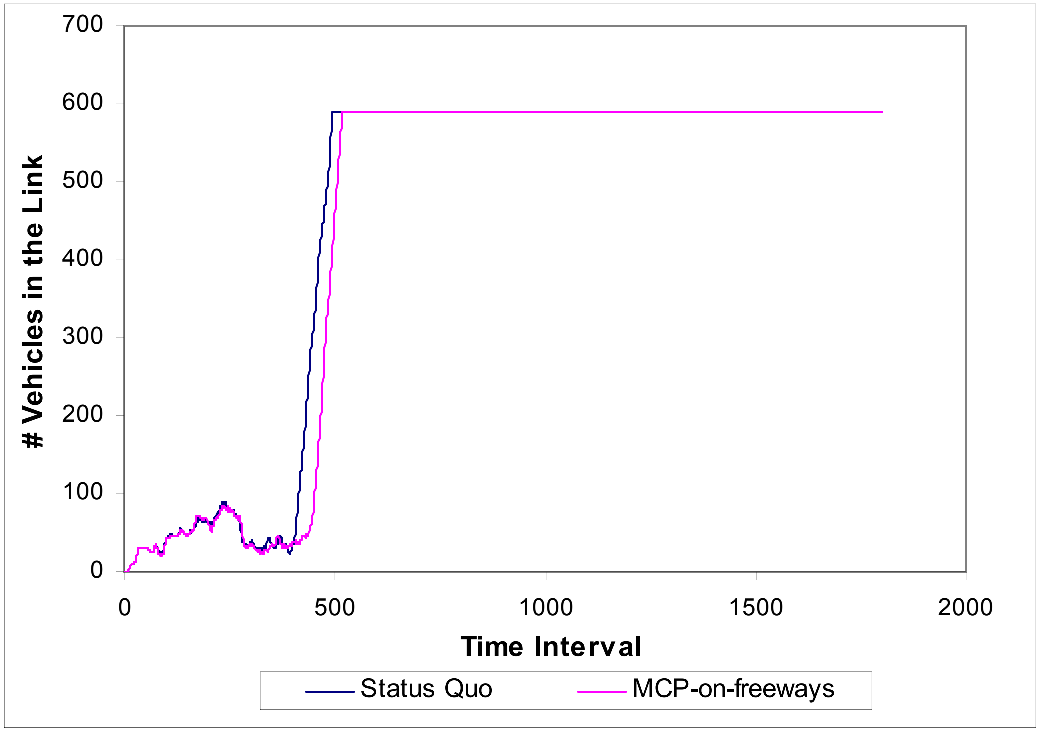


Figure 9.14 Time-Varying Traffic Flow of Freeway Link ID 22171

(IH30 WB, Near GALLOWAY)
(Length = 2112 ft, MCP Toll Rate Max = $0.04/mile)
(Total Vehicles = 815561 for Status Quo, 798301 for MCP-on-freeways; Capacity = 4300 vph)

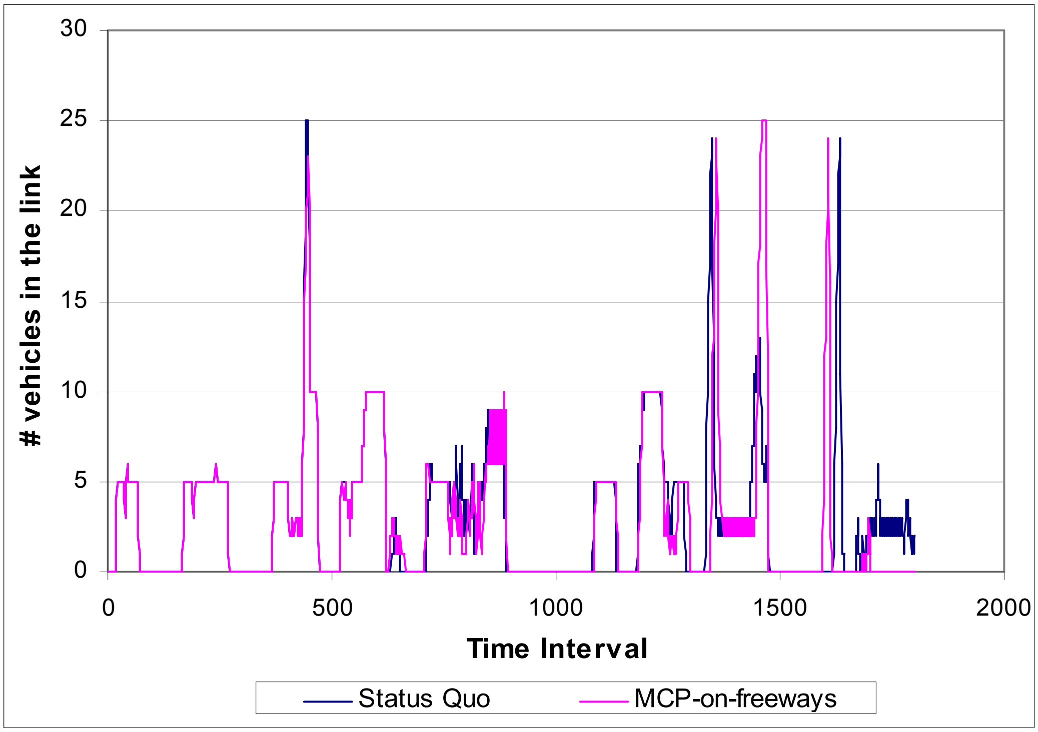


Figure 9.15 Time-Varying Traffic Flow of Freeway Link ID 19017

(IH35W NB, Near Meacham)
(Length = 1742.4 ft, MCP Toll Rate Max = $0.22/mile)
(Total Vehicles = 5468 for Status Quo, 5295 for MCP-on-freeways, Capacity = 4450 vph)

9.7 Limitations in DTA Models

This DTA analysis assumes inelastic demand, in both destination and mode choice, substantially limiting behavioral changes. Due to computational limitations in VISTA, the numbers of vehicle trips for the status quo and MCP-on-freeway scenarios between all OD pairs come from the static analysis (the applications of joint DM choice model [Gulipalli 2005]), and these are considered fixed. Departure times are also considered fixed. Although VISTA's path-based simulation model can assume different VOTTs across OD pairs (as explained in Ziliaskopoulos et al. 2004), a single VOTT of $10 per vehicle-hour was used here, since it is more comparable to the STA approach and no obvious means of ascertaining VOTT variations by OD pair was available. The centroid structure was aggregated to enable DTA analysis. The static demand is smoothed across times of day by the proposed optimization model. Finally, the MCP toll calculation is an approximation method, unlike the analytical method in the STA.

9.8 Conclusions for DTA Analysis

Three modifications of the VISTA software were made for this project's congestion pricing analysis. First, the time-dependent shortest path algorithm was modified so as to account for the toll prices with the assumption of homogeneous users. Second, a new demand profiling algorithm that smoothes the OD travel demand over a 24-hour period was proposed and applied (instead of distributing demand uniformly over time). Third, a heuristic dynamic MCP module was developed, employing the link marginal congestion costs to calculate the time-dependent toll. With these three modifications, two DTA schemes in VISTA were built for the two scenarios: status quo and MCP-on-freeways. This represents a wholly new application environment for VISTA and a major step forward for this kind of DTA model.

The 1999 DFW roadway network was converted from TransCAD format into VISTA format. Due to computer memory limitations, DFW's past, more aggregated zonal system was used, composed of 919 zones/centroids and 3,642 centroid connectors. The network structure used in the dynamic analysis was the same as the static analysis, but the analysis focused on the AM peak (6:00 AM–9:00 AM). The time-dependent OD demands for the status quo and MCP-on-freeways scenarios were the same, as derived from the status quo of the static analysis. The DTA link-performance parameters are the following: the assignment interval of ten minutes, the simulation time step of six seconds, and the single value of travel time (VOTT) of $10 per hour. For both scenarios, the DTA module was run for five iterations, followed by running the update-cost-DTA module until convergence.

The results of static and dynamic traffic assignments were remarkably inconsistent. The reasons for this are felt to be as follows. (1) The STA approach allowed behavioral feedbacks, whereas the DTA did not. (2) The time periods and traffic demand profiles were distinct (AM and PM peak period constant-demand STA results were compared to AM-only DTA results for a linearly increasing [over time] demand level). (3) The STA's BPR parameters were based on effective capacity (essentially maximum service flow under level of service C, rather than true capacity, under LOS E) and thus were biased low, yielding higher speeds and shorter travel times; in contrast, the DTA model parameters may result in biases that overestimate the level and extent of spillbacks and congestion. (4) The DTA's marginal cost pricing (MCP) method is an approximation, whereas that in STA is analytical. (5) The DTA zone and centroid connection structure was relatively coarse, so the DTA network could not load (and unload) as smoothly as the STA network. Minor changes in DTA-predicted freeway use following implementation of MCP-on-freeways suggest that short-trip travelers may avoid the priced freeways, while longer-trip travelers are more willing to pay the congestion tolls.

Using the DTA-based approximation method described in Appendix I5, MCP tolls on freeways during the AM peak period were predicted to range between $0.1 and $29.2 per mile. Predicted freeway link densities and associated MCP tolls indicated observable shifts in traffic flows due to pricing. Some minor system benefits were observed, including a delay in the onset of congestion. Of course, traffic impact predictions would have been much more dramatic had behavioral feedbacks been incorporated. Future implementations should allow such feedback, to incorporate destination, departure-time, and mode-choice decisions. However, such improvements are very challenging. It is not clear when a model as complex as VISTA will achieve this. In the near term, STA models may be best for an idea of behavioral response, with DTA-type models used to provide more information on queue formation. Greater comparability between DTA and STA methods will be needed, however, before this can be done. As was evident here, results can differ dramatically, and the causes of such differences may be very difficult to remove. Perhaps TransCAD's DTA approximator will provide the needed comparability, while offering a practical opportunity for such policy evaluations (see Kockelman et al. [2006] under TxDOT project 0-4637 "The Role of Toll Projects in Enhancing Texas Transportation").

10. Summary of Project Results

10.1 Introduction

Demand management seems to be the key to congestion alleviation, given the high costs of capacity addition that is then often "undermined" by latent demand. Pigou (1920), Knight (1924), and Vickrey (1963) were some of the pioneers of demand management, in the form of road space rationing and congestion pricing (CP). However, one of CP's main drawbacks is the issue of equity. Researchers have suggested different solutions to overcome this, including commuter credits (Small 1992), income tax reduction (Parry and Bento 2001), FAIR lanes (DeCorla-Souza 1995), roadspace rationing (Daganzo 1995), and providing 'mobility rights' (Viegas 2001) to name a few.

Kockelman and Kalmanje (2004) proposed a credit-based congestion pricing (CBCP) policy that has the potential to allay CP's equity concerns. CBCP provides travelers with 'credits' to use on travel (or anything else). Individuals who exhaust their monthly 'credit' allowance will have to pay out of pocket to keep driving. Kockelman and Kalmanje (2004) surveyed the Austin public and found that support for CBCP was comparable to other transportation policies. They concluded that educating people about the merits of CBCP and simple experience with roadway tolling could significantly affect public perceptions. In a related work, Kalmanje and Kockelman (2004) predicted Austin area trip-based welfare impacts and land value changes under CBCP. They found that CBCP was expected to benefit most residents, unlike CP, which was predicted to benefit only a few.

Recognizing CBCP's potential as a viable and equitable congestion mitigation tool, this work strived to develop the policy further. Implementation of any significant transportation policy requires an understanding of the policy's various impacts (short term and long term). Therefore, the following data was gathered and analyzed in order to refine the details of the CBCP policy.

- Interviews with stakeholders and related experts
- Consideration of various uses of CP revenues
- Modeling of traveler behavior using joint destination-mode (DM) choice models and application to the DFW region
- Evaluation of traffic and air-quality impacts for two MCP scenarios in the short run and the long run[17]
- Examination of welfare impacts and dynamic traffic assignment results
- Evaluation of toll technologies and estimation of CBCP implementation costs and predicted tolls/travel budgets

[17] Long run here is taken to mean the models where work-trip destination choices are permitted to vary between the status quo and MCP scenarios. Such a shift in work locations would be very difficult to imagine for most workers in the short run. Over the longer run, land use changes would also occur under pricing; however, these were not modeled here, due to the complexity of the behavior and the time required to specify, calibrate, and apply such models.

A summary of this work, along with some final CBCP policy recommendations, is provided below.

10.2 Stakeholder and Expert Perspectives

In prior work Kockelman and Kalmanje (2004) examined public opinion of CBCP. As a complement, this project conducted an extensive survey of stakeholders and experts. The respondents included academicians and practitioners in the fields of transport economics, toll technology, administration, and policy. Fifty of the 140 contacted individuals responded. The survey revealed a series of useful, and sometimes conflicting, opinions. Commercial users seemed supportive of the policy, since it would improve travel time reliability, and transport economists generally were quite positive. However, policy makers expressed concern over CBCP's public acceptance, and many respondents were concerned about CBCP's administrative costs.

Toll revenue utilization is a key issue, since public opinion largely depends on how revenues are used. If CBCP policy were not revenue-neutral, investment in existing roadway maintenance and capacity addition was the foremost choice of the respondents. While generally receptive to the idea of CBCP, respondents expressed concern about public opposition to tolling, privacy issues, record keeping, travel budget allocation, and equity issues. Travel budget allocation was the most significant concern; most of the respondents were not in support of equal budget allocation. Compact land development was expected, and the impact on state and local economies was expected to be marginal (either way). The toll technologists recommended using radio frequency (RF) tag technology for CBCP while mentioning global positioning system as a potential technology. They suggested automated number plate recognition (ANPR) for toll enforcement, though a few privacy concerns were raised.

Commercial users who depend heavily on timely product and service delivery indicated willingness to pay a premium to guarantee such deliveries. Office-based commercial users indicated a willingness to support some congestion mitigation policies in an effort to reduce regional pollution levels. Nearly all employers did not anticipate paying for CBCP-related charges incurred by their employees. As the outsourcing of transportation and distribution become more ingrained in business models, incentives for timely delivery no longer reside so much in these commercial entities but in their shippers and couriers. This trend may undercut the incentives that reduced congestion levels might bring to many commercial users. However, it seems that there is strong support for tolling among experts and policy makers to manage congestion based on current technologies. The next section provides a summary of CP revenue uses.

10.3 Alternative Uses of CP Revenue

This study examined various CP revenue use options. In general, experts emphasized that revenues should be invested so as to generate public support while enhancing public welfare. However, the details of their recommendations did diverge. Suggestions included tax reduction, travel allowances, network expansion, and transit improvements among others. Caveats apply in all cases, and a variety of uses may be undertaken at once. For example, sales tax reductions apply to a region's population globally, while income tax reductions primarily benefit workers (and thus, commuters). Travel allowances may go to all licensed drivers, just commuters, or just disadvantaged travelers; however, such allowances can entail additional administrative costs.

Roadways may be expanded through addition of lanes or addition of links, or they simply may be better maintained. Transit expenditures may be pointless in regions where transit is not a reasonable alternative; in such cases, transfers or travel credits may make the most sense. Of course, the operational and administrative costs of a CP policy are not insignificant, and those costs must be covered. However, in order to keep administration costs low, certain policy options may be preferred. For example, rather than distributing cash credits widely (as under CBCP), tax reductions may be pursued.

Since different populations experience different impacts, it may be wise to apply CP revenues for various purposes, thus benefiting a wide segment of society. For a discussion of current field practices in use of CP revenues, please refer to Appendix C2. Appendix C3 summarizes user opinions of selected road pricing projects. The choice of such purposes ideally should depend on expectations of policy impacts, by a person's home location, income bracket, and travel needs, since impacts will differ. However, such predictions are complex and uncertain. Appendix C1 provides a discussion on political acceptability of revenue use. Thus, after considering all the options discussed herein, it may be best to stick with a broad-based tax reduction policy, travel credits for certain disadvantaged groups, and capacity expansion in locations most affected by continuing congestion, even after CP is implemented in a region.

10.4 Technology Evaluation and Review

A synthesis of some of the experiences from recent congestion pricing demonstration projects and a formal procedure for evaluating the appropriateness of various technologies were developed. One benefit of the synthesis was the development of more precise measures of performance to evaluate the potential technologies. Subsequently, the evaluation was conducted, using ELECTRE IV (a state-of-the-art evaluation algorithm that overcomes many of the traditional drawbacks of other evaluation approaches). The usefulness of the approach was demonstrated on a subset of technology, some of which were tested in the PRoGReSS demonstration projects. The most appropriate technology for Texas was determined to be radio-frequency identification (RFID) in the near term. However, in the longer term, the research team believes that the digital short-range communication (DSRC) technology should become a better choice as the affordability increases.

10.5 Travel Demand Model Estimation and Application

Instead of using a traditional gravity model for trip distribution, this study modeled destination choice. Joint destination-mode (DM) choice models predict the trip-end (attraction zone) choice of an individual traveler and also his/her travel mode. This study used zonal characteristics, demographics, travel time, and cost variables to model this choice for three different trip purposes: home-based work trips, home-based non-work trips, and non-home-based trips.

Additional transit records from the transit on-board survey were used in order to better represent the transit trips. The ODs were converted to productions and attractions (PAs), and demographic information was appended. Additional records with the same production end and random attraction ends were created for each trip record, and appropriate LOS data was appended from the relevant LOS files. Zonal characteristics were also appended and then weights computed, based on mode shares in the household survey, and the final data set used for modeling. An operating cost of \$.30/mile was assumed for DA and SR trips. Walk-bike times were computed assuming an average speed of 5 mph; the costs were assumed to be zero. The values of travel time (by income group and trip purpose) were constrained in the joint DM choice models. The log of generalized cost was used in the models since it fit the data better than a linear form. The model estimates for different trip purposes were provided.

Joint DM choice models were applied to the DFW metroplex. Three scenarios were simulated: Status quo, MCP-on-freeways, and MCP-on-all-roads. Links coded in the network numbered 22,187. NCTCOG provided zonal productions for each trip purpose for six demographic groups based on income category and vehicle ownership. The joint DM choice model was used to compute the probabilities of different DM alternatives, which were used to compute the PA matrices. Trip return rates and average vehicle occupancy information, obtained from the survey, were used to convert the PA matrices to OD matrices. OD matrices were aggregated across demographic groups and trip purposes to give OD matrices for each time period and mode (DA and SR).

TransCAD's multi-modal multi-user module was used for assigning OD flows on to the road network (using stochastic user equilibrium). Different networks were used for SR and non-SR trips based on availability of high occupancy vehicle lanes. The standard Bureau of Public Roads (BPR) formulation was used to define volume-delay relationships on the links. The method of successive averages (MSA) was used to equilibrate the (full) feedback model (rather than using direct feedback). The analysis does not allow departure time shifts across the five time periods used. The results of TDM application include link flows and speeds. These and other traffic outcomes across various scenarios are summarized in the following section.

10.6 Traffic Impacts

The traffic impacts for the MCP-on-freeways and MCP-on-all-roads scenarios were compared with the status quo. The 1999 DFW network links are divided into eight categories (e.g., freeways, HOV and principal arterials), with 14 percent of lane-miles as freeways and another 14 percent as principal arterials.

VMT for both MCP scenarios was predicted to fall by about 7 percent, indicating that people tend to choose nearer destinations and/or shift from DA to other modes in the presence of pricing. Freeway VMT fell by more than 12 percent for both scenarios (relative to the status quo). The mode shifts were very marginal (<2 percent) in favor of transit and walk/bike modes, indicating that travelers are more likely to change destination and/or routes rather than change their modes. However, this impact might be felt by transit agencies, as the shifts represent a 15 percent increase in transit ridership estimates.

A comparison of VMT at different V/C levels suggested a reduction in congested travel for MCP scenarios. For MCP-on-freeways, VMT at V/C > 1.5 was predicted to practically disappear in the short run, and fall about 73 percent in the longer run. A corresponding increase in VMT at lower V/C levels was predicted, indicating a shift to relatively uncongested routes. Daily VHT was predicted to fall by about 6 percent for the MCP-on-freeways scenario, and 10 percent for the MCP-on-all-roads scenario, in the short run. This was predicted to fall further in the long run, as travelers were permitted to change their work trip destination choices.

VMT and link speeds predicted by the model for the status quo were compared with NCTCOG's estimates. Though the total VMT figures compared well, the current study predicted considerably higher speeds. This was mainly because of different link performance functions used by the two studies and post-processing of the speeds by NCTCOG. Overall, the MCP scenarios suggested significant relief on congested links, as indicated by the increase in the predicted speeds on all facilities. The MCP scenarios, as expected in theory, seem to be successful in enhancing road space allocation. The travel benefits to various neighborhoods across user groups were computed as the welfare change (change in consumer surplus). The results of this work are summarized in the following section.

10.7 Welfare Changes

Home location and user preferences for travel modes and trip destinations determine estimates of travel benefits arising under a CBCP policy. The change in consumer surplus is a holistic measure of travel benefits. This was computed as the difference in the probability-weighted systematic utilities or logsums of all DM choices for the two comparisons (i.e., status quo vs. each of the two MCP-with-travel-budget scenarios). The welfare change for all user groups at each trip-producing zone was converted into monetary units using the marginal utility of money. The $0.68/day CBCP travel budget estimate was added to this value, and the distributions of welfare changes for different user groups were plotted for the CBCP on freeways scenario (Figures E2.1–E2.6 in Appendix E2).

CBCP policy benefits, as measured by the net welfare estimates, were predicted to be the highest for users near the CBDs, with net benefits predicted to average about $.40/day. Users in north DFW (excluding the Denton and McKinney CBDs), the northwest regions (to the immediate west of Carrollton), and south DFW (between Cleburne and Waxahachie) were predicted to lose the most, approximately $0.30/day. While pre-budget losses are predicted to be less for the MCP-on-all-roads scenario, in comparison to the MCP-on-freeways scenario, there will less net revenues from such a scenario, after covering the cost of technology deployment and policy implementation across the region's roads. So, net benefits may be much less than under the MCP-on-freeways scenario.

The predicted spatial distribution of welfare changes for a CBCP policy has implications for credit distribution. If differential budget allocation is advocated, eligible users in regions that are the less likely to benefit (such as northwest and south DFW) could be considered for larger travel budgets. Alternatively, some portion of CBCP revenues could be invested in those regions. The results of these analyses suggest welfare gains to a majority of the users under a CBCP policy on freeways. Benefits may be greater if tolls are more optimally calculated (recognizing that the entire system is not priced, so MCP tolls are higher than optimal). These results reinforce CBCP's role as a welfare-enhancing congestion-mitigation tool.

The reader should note that the welfare changes do not include any air quality benefits, which were estimated as change in mobile emissions for the three scenarios. This is summarized in the following section.

10.8 Emission Estimates

MOBILE6 was used to compute mobile emissions estimates for DA and SR trips for the three scenarios: Status quo, MCP-on-freeways, and MCP-on-all-roads. TDM application results were used to compute VMT and speeds for every link in the network. These were used to estimate emissions for every link, which when aggregated over the network and over the day gave the daily estimates. Inputs for MOBILE6 include vehicle speed, fuel characteristics, temperature, vehicle age, and soak time distributions, among others.

Emission rates as a function of vehicle speed were computed for four pollutants (HC, CO, NO_x, and CO_2) and particulate matter (PM2.5 and PM10) using MOBILE6. MCP-on-freeways was estimated to reduce the status quo emissions estimates by about 7 percent vs. 8 percent for MCP-on-all-roads in the long run. Thus, as with VMT, MCP-on-freeways seems to have significant effect on air quality also. The results indicate that MCP scenarios cut down health hazards from mobile emissions.

Based on these and prior results, particularly expert perspectives, CBCP policy recommendations were developed, as summarized below.

10.9 Dynamic Traffic Assignment

A simulation-based dynamic traffic assignment (DTA) was employed to evaluate the status quo and the MCP-on-freeways scenarios. Due to VISTA's tremendous computational demands and the great complexity of the DFW network, the status quo and the MCP scenario were simulated for only the three-hour AM peak period, and without behavioral feedbacks (to destination, route and time-of-day choices). Given static demand results for five periods across the day, a smooth demand profile was generated for the AM peak every six seconds. MCP toll were updated every five minutes. Dynamic prices varied substantially over the analysis period, reflecting changes in congestion. When prices were imposed, some minor system benefits were observed, including a delay in the onset of congestion. If feasible, future implementations should seek to incorporate destination, departure-time and mode-choice decisions.

10.10 Policy Recommendations

Kockelman and Kalmanje (2004) first explored public perceptions of their original CBCP policy proposal, and Kalmanje and Kockelman (2004) then examined the policy's short-term traffic and land value impacts for Austin, Texas. This study folds in stakeholders' and experts' opinions and predictions of long-term system impacts to produce recommendations for an even more refined CBCP policy. The revised CBCP policy proposal and associated implementation strategies aim to address stakeholders' and experts' concerns relating to the original policy proposal, including ease of implementation and use of revenues. Instead of offering cash credits to all licensed drivers in a "region," travel credits only for registered vehicle owners are recommended (to minimize administrative burden and potential for fraudulent claims). The specific political atmosphere and financial constraints may govern whether cash-outs will be allowed. Travelers with special needs may apply for additional travel credits, and unreturned revenues may be reinvested in the transportation system. Options for addressing issues like budget eligibility, system visitors, enforcement, and toll collection methods are suggested in Chapter 8. This study concludes that RFID tags and ANPR are most the appropriate implementable technology for the near term. In addition, conservative estimates of initial and recurring costs of implementing a CBCP policy along DFW freeways were developed; these are estimated to be about \$55 per DFW resident when annualized. When allocated uniformly across eligible individuals, monthly net revenues is estimated to result in a travel budget of about \$15 per eligible individual[18] in the short term and \$6 in the longer term. The simulation results suggest that CBCP has significant potential for congestion alleviation on freeways and net traveler benefits across the region.

[18] In this work, eligible drivers are assumed to be 70% of the vehicle population in DFW.

Hence, CBCP can be a very valid option for congested cities looking for a viable road pricing strategy.

Taking such a novel proposal such as CBCP from its theoretical foundation to everyday practice can involve considerable challenges. This work strives to advance the concept and address anticipated hurdles. One of the strengths of CBCP is its flexibility in implementation in regards to pricing decision, vehicle identification technology, enforcement, and budget allocation. Regions with extensive, congested transit systems could consider CBCP for those systems as well. More congested systems may want to retain more CBCP revenues for system enhancement. Smaller communities may opt for cashable credits, rather than travel credits that expire each month. CBCP in its current form has been galvanized by expert perspectives and is now a feasible demand management strategy. This study suggests that CBCP can help tackle the problem of congestion in an economically viable, equitable, and efficient fashion. As such, CBCP is a powerful idea with significant potential.

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Appendix A1: Road Pricing Case Studies

San Diego's Interstate 15 (I-15) CP Project

The information about San Diego's CP project mentioned in this section is taken from Supernak et al (2002a) and Supernak et al (2002b). I-15, in San Diego consists of an underutilized express lane (8 miles in each direction) and four to five severely congested normal lanes. In December 1996, as a solution to this problem, the express lanes were priced for use by Single-Occupancy Vehicles (SOVs). Phase I of the project was the ExpressPass program, where the SOVs had to pay a flat toll of $50.00/month, later increased to $70.00/month, for unlimited use of the express lanes. After 15 months Phase II, the FasTrak program, was implemented. Dynamic pricing was employed to maintain Level of Service (LOS) C on the new FasTrak-only lanes. The toll varied between $0.50 and $4.00 per trip (roughly $0.06 to $0.50/mile) and could reach $8.00 ($1.00/mile) under extreme congestion. Phase II employed automated vehicle identification (AVI) and windshield mounted transponders. The FasTrak-only lanes were removed in July, 1999 because of problems in merging and diverging. However, FasTrak program continues on the express lanes. To distinguish the effect of pricing I-15 from the effects of other factors, Supernak et al (2002a and 2002b) studies used a commuter route I-8 as reference or control corridor. Their evaluation was based on a panel data set (from Fall 1997 through Fall 1999).

Supernak et al (2002a) noted that the increase in overall traffic was slightly greater on I-8 than on I-15 (8 percent versus 6 percent). However, the express lane volumes increased by 48 percent over the three-year period. Evidently, pricing alleviated congestion on the main lanes by redirecting some traffic onto the express lanes. The SOV volume on I-15 increased substantially, while the HOV volume decreased. This may reflect the general economic boom during the study period. However, HOV shares on I-8 and on I-15's main lanes were much lower than those on I-15's express lanes. LOS C was maintained at all times on the express lanes. FasTrak's dynamic fee structure was able to redistribute traffic from the peak to the shoulders. The ExpressPass with its flat toll structure was unable to do so. Travel times increased both on I-15 and I-8 because of increases in travel volume. FasTrak users saved up to 20 minutes by avoiding travel on the congested main lanes during peak-periods. The increase of emissions along I-8 was three times larger than that along I-15 in the AM peak and five times as large in the PM peak.

Supernak et al. (2002 b) assessed the impact of pricing on travel behavior, perceptions of travel conditions and attitudes. They surveyed individuals from three user groups: ExpressPass and FasTrak users, users of I-15's main lanes, and I-8 users. Their comparisons suggested that FasTrak customers were more highly educated and earned more than I-15's main lane users. They were predominantly home owners and from two-vehicle households and were likely to be middle-aged women.

Evidently businesses found the FasTrak pricing system to be less attractive, since it was costlier than the ExpressPass system (which was priced monthly for unlimited use). However, the implementing authorities perceived the project to have exceeded their expectations. Supernak et al (2002a, 2002b) concluded that both forms of pricing, fixed and dynamic, were operationally successful, and HOV lanes can be better utilized by CP. Also, unlike flat tolls, dynamic pricing can redistribute peak-traffic to the peak-period shoulders. CP seemed to increase reliability, travel time savings and safety and is a technologically and politically viable policy.

Bridge Pricing in Lee County, Florida

The details of this case study have been taken from Burris et al (2000) and Cain et al (2001). As a pilot project to understand driver responses to variable tolls and to alleviate congestion levels, variable pricing was adopted on the Midpoint Bridge and a few other bridges in Lee County, Florida. A $1.00 flat toll was initially charged to help finance the bridge construction. Later, a variable pricing discount program was implemented, where tolls were reduced by 50 percent in the peak-shoulders (6:30 am to 7:30 am, 9:00 am to 11:00 am, 2:00 pm to 4:00 pm, and 6:30 to 7:00 pm) for people paying tolls electronically (i.e. via AVI debit accounts).

People who did not use ETC paid a $1.00 flat toll manually, by stopping; and people using ETC, eligible for the discount, paid $1.00 in peak-hours and $0.50 in peak-shoulder hours while driving through the toll plazas typically without stopping or appreciably slowing. Burris et al (2000) analyzed data for ETC and non-ETC users separately over half-hour periods and compared any observed changes. Burris et al (2000) suggest that variable pricing had a minimal impact on the overall temporal distribution of travel demand. Deviations from the pre-discount scenario were slight for ETC users and non existent for others. Comparison showed that variable pricing has a minimal impact on total travel demand.

Cain et al (2001) carried out a more disaggregate analysis by computing the percent changes in demands over half-hour periods. They observed positive shifts in demand in peak-shoulders (discount periods) and negative shifts in peak-periods for ETC users. Also, the morning peak impact was greater than the afternoon peak impact. The greatest observed impact was at the boundaries between the peak and peak-shoulders. This was expected since the likelihood of people changing their travel times is directly related to the level of travel time benefits they make. Cain et al (2001) calculated price elasticity, (defined as the percent change in demand per percent change in cost) at different times of day. The authors used a peak-hour-to-peak-period-ratio (PHPPR) to quantify peak-spread. The PHPPR of the morning peak on Midpoint Bridge was 44.7 before variable pricing and 41.6 after variable pricing. A correlation between the percentage reduction in peak-period demand and PHPPR also was found.

London's Cordon Toll

To alleviate congestion in London, one of the world's most congested cities, a cordon toll was adopted. Motorists are now required to pay £5 (approximately US $8.90) to enter central London on weekdays between 7:00 am and 6:30 pm (with weekly, monthly, and annual payment plans also available). Taxis, disabled persons, motorcycles, buses and emergency vehicles are exempted. And people residing in central London receive a 90 percent discount. Users may pay at payment machines installed at various locations, on the internet, at select retail outlets and by cellular telephone messaging. A network of video cameras records vehicle license plate numbers and matches each with a list of numbers that have paid the charge, so as to penalize violators. This pricing system is not considered optimal since it is not dynamic, does not vary by location, does not depend on miles traveled, and requires a high initial investment. However, it is simple to understand and many cameras were already installed to monitor terrorist activities.

Litman (2003) summarized the policy's initial traffic impacts. During a typical weekday peak-period around 85 percent of the trips are made by public transport. The mode share of private automobiles was 12 percent prior to pricing and 10 percent after pricing. Users with high-value trips benefited while those with marginal value trips were negatively affected. The majority of people who changed their travel patterns shifted to public transport, while the rest switched to walking, bicycles, motorcycles and other strategies, and those passing though central London preferred to bypass it. As a result of all these changes, the average speeds in central London increased by 37 percent (8 mph to 11 mph). Peak congestion delays fell by 30 percent, while bus congestion delays halved. Overall efficiency increased. People seem to have accepted this policy after much resistance. A large majority of businesses said that the pricing has had no effect (69 percent) or a positive effect (22 percent) on them. An employee earning average London wages (£ 34,000 per year) would make up for the £ 5 charge with a 17 minute travel time saving. Litman (2003) concluded that London's successful implementation suggests that pricing is technically and politically feasible.

Singapore's Congestion Pricing

The growing demand for vehicles in Singapore was much more than what its road network could handle. The Singapore government responded to the congestion crisis early on, by implementing a number of congestion management policies. The following section discusses these policies and their results in a chronological order.

In 1972 the Singapore government increased the cost of buying a car by imposing a 25 percent tax on vehicle purchases and raising the import duty on cars from 30 percent to 45 percent, yet the demand for vehicles kept increasing. Goh (2002) attributes the cause for the failure of this Additional Registration Fee policy to the country's economic boom. So the government implemented the Area Licensing Scheme (ALS) in 1975. CBD access was restricted from 7:30 am to 6:30 pm on weekdays by supplementary licenses. As a result traffic in the restricted zone decreased by 45 percent, while the target was only 25-35 percent (Phang and Toh, 1997). However, traffic increased during non-ALS hours.

In 1988, the government increased the region's road taxes and parking fees at public-housing developments by 100 percent, followed by a significant gas tax, to curb further VMT growth. These policies failed to achieve their objective. In 1990 a Vehicle Quota System was implemented. One had to successfully bid for Certificate of Entitlement at monthly auctions to own a vehicle. Many times the bids exceeded US $58,000.00 for luxury cars, causing frustration among aspiring car owners (Goh 2002). Foo (1998) writes that several studies argue this system is administratively cumbersome and inconvenient for the car-owning public, and hence should be abolished

In 1995 the Singapore government priced expressways to regulate traffic on them (via manual payment toll plazas). About 16 percent of the motorists stopped using the expressways during the Road Pricing Scheme's (RPS) active hours (7:30-9:30 am). However, traffic worsened just outside the RPS-controlled zones as users began to seek non-RPS routes (Goh, 2002). In 1998 the government implemented Electronic Road Pricing (ERP) via RFID transponders. A major concern was fear of pubic rejection because of privacy concerns, as in Hong Kong (Hau, 1990) and the Netherlands (Phang and Toh, 1997). So Singapore used a less intrusive ETC system. The ERP system resulted in traffic spreading over the day, keeping expressways free flowing and arterials free relatively less congested. ERP was a success since the cars need not slow down and drivers need not carry exact change (Goh, 2002).

Appendix A2: Suggested Survey on CBCP for DFW residents

Survey Title:

Consideration of a New Roadway Policy: Credit-based Congestion Pricing

Dear Resident,

As researchers at the University of Texas at Austin, we are conducting a study to explore a strategy for reducing traffic congestion in the Dallas-Fort Worth (DFW) region. We wish to assess public opinion of and traveler response to implementation of a Credit-Based Congestion Pricing (CBCP) policy on several major highways in the DFW region. (e.g., IH 35E, IH 45, US 175, IH 30, US 75, IH 35W, SH121). CBCP could be very beneficial in rationing highways (existing or new); however, the region is not proposing the implementation of CBCP at this time. The region currently has a policy against any tolling of existing lanes. The University of Texas in conjunction with TxDOT is merely conducting research at this time. Your input will be very valuable in helping assess the challenges and possible solutions to this idea.

A CBCP policy would provide a travel budget at the beginning of each month, free of charge, to all regular users of congested roads. During congested periods of the day (i.e., "rush hours"), all users of congested roads would be charged to use such roads. For the regular users, this charge would be electronically deducted from their monthly budget. Drivers exceeding their budget before the end of the month would be required to pay "out of pocket" to drive during rush hour. Drivers with any unused budget at the end of the month would receive cash for their unused credits. Thanks to new technologies, such solutions to congestion are becoming viable, even for local streets.

Please take a few minutes and fill out the attached survey. The survey will ask questions about you and your travel habits. Be assured that your responses will be kept in strict confidence and there is no risk involved in your participation; it will require only a small portion of your time. You are not obligated to participate in the survey and you can withdraw anytime. However, your input and opinions are very important to us, since it is critical that all perspectives and travel behaviors be represented, in order to accurately represent community response.

If you have any questions or comments about this study, please feel free to contact me personally at (512) 471-0210. ***Thank you very much*** for your time and cooperation.

Sincerely,
Kara Kockelman
C.B. Luce Associate Professor of Civil Engineering

1) What is your employment status?
- ☐ Employed Full-Time
- ☐ Employed Part-Time
- ☐ Student
- ☐ Unemployed
- ☐ Retired
- ☐ Other (please specify):________________

2) If you work or attend school, how far do you travel to work/school one way?
_______ miles (Please enter "0" if you work from home.)

3) If you work or attend school, how flexible are your work/school hours?
- ☐ Very flexible: Can shift work hours more than 2 hours either way
- ☐ Somewhat flexible: Can shift work hours up to 2 hours either way
- ☐ Not flexible at all: Cannot shift work hours
- ☐ Other____________
  (please specify)

4) Had you ever heard of **congestion pricing** (where tolls are charged during peak-periods to reduce congestion) before this survey?
- ☐ Yes If yes, where: ____________________
- ☐ No

Imagine you are a driver in the given scenario, and please answer questions 5-8 accordingly:
A Credit-Based Congestion Pricing (CBCP) policy has been implemented in the DFW region. Tolls are set at 20 cents per mile for driving a vehicle during peak-hours on congested freeways (e.g., IH 35E, IH 45, US 175, IH 30, US 75, IH 35W, SH121). Biking, walking, bus, and rapid transit trips, however, are not subject to tolling. Under the new policy you are given a *monthly* travel budget (say $50.00) if you are a vehicle owner. Once you have used up your budget, you have to pay for any additional peak-period trips on congested roads. Any unused travel budget will be returned to you as cash. TollTag/transponder technology will be used for collecting congestion tolls and distributing monthly travel budgets.

PEAK-PERIOD: 6:30 am to 9:00 am and 4:00 pm to 6:30 pm
TRIPS: Count side trips on the way to/from work as separate trips, unless they are for child care/school drop off. For example, if you stop at a grocery shop while returning from work then you are making one work trip and one non-work trip. Count round trips as two separate trips.

Please skip to question 6 if you are unemployed/retired.

5a) In the table below, please indicate how many **PEAK-PERIOD WORK** trips (**SCHOOL** trips if you are a student) you currently make in a **WEEK for each mode of travel**, and how many you would make if CBCP were implemented.

	Number of **WORK/SCHOOL** trips per **week**	
Travel Mode	Currently	Under CBCP
Drive alone trips		
Carpool trips		
Walk & bike trips		
Transit trips (Bus &/or rail)		
Other mode of travel: ________________ (please specify)		

5b) In making fewer peak-period work/school trips under CBCP (if not skip to Q6), you are
- ☐ Making some trips in the off-peak period
- ☐ Forgoing some trips
- ☐ Both (making some trips in the off-peak period & forgoing some trips)

6a) In the chart below, please indicate how many **PEAK-PERIOD NON-WORK** trips (visits to friends, gym, outdoor activities, shopping, eating out, etc.) you currently make in a **week**, and how many you would make if CBCP were implemented.

	Number of **NON-WORK** Trips per **week**	
Travel Mode	Currently	Under CBCP
Drive alone trips		
Carpool trips		
Walk & bike trips		
Transit trips (Bus &/or rail)		
Other mode of travel: ________________ (please specify)		

6b) In making fewer peak-period non-work trips under CBCP (if not skip to Q7), you are:
- ☐ Making some trips in the off-peak period
- ☐ Forgoing some trips
- ☐ Both (making some trips in the off-peak period & forgoing some trips)

7) If CBCP were to be implemented across the DFW region's highways, would you change where you live, work, obtain child care, shop or recreate? Please let us know how likely it is that you would change the location of each of the following:

	n/a	very likely to change	likely to change	unlikely to change	very unlikely to change
Residence	☐	☐	☐	☐	☐
Work/school	☐	☐	☐	☐	☐
Childcare	☐	☐	☐	☐	☐
Shopping	☐	☐	☐	☐	☐
Recreation	☐	☐	☐	☐	☐

Please skip to question 10 if you do not travel to work/school.

8a) Assume that it currently takes you 45 minutes to travel to work/school. If your commute would require only 30 minutes thanks to a new congestion-reducing policy, how much would you be willing to pay for this 15 minutes of time saving?

$_____.___ for 15 minutes time savings

8b) If it currently takes you anywhere between 45 and 75 minutes to travel to work/school and a new traffic policy reduces both the travel time and travel time variability so that it consistently takes between 25 and 35 minutes, how much would you be willing to pay?

$ ____.___ for 15 minutes of time savings and 67 percent more consistency in travel time

9) Say a round trip to work/school by ***bus*** requires *60 minutes more per day* than driving. What are you willing to spend on tolls each day before you switched to taking the bus?

$_______ per day

☐ Not applicable (I do not drive)

10) If you were to receive **$50.00 each month** in your toll tag account (to use on congested roads or cash in), would it influence your travel behavior?

☐ I would *not* change my driving behavior. (I would pay additional tolls as necessary, or use excess cash for other purposes.)
☐ I would drive less to try to save money
☐ I would drive more to use my travel budget or to take advantage of less congested roads. I expect that I would spend $________ *more* per month on tolls.
☐ Not applicable (I do not drive.)

10.5) Say the amount you receive each month is currently cashable. If the policy is changed so that cash out is not possible, would it influence your travel behavior?

☐ I would *not* change my driving behavior
☐ I would drive more to use my travel budget (which cannot be cashed out)
☐ Not applicable (I do not drive.)

11) If you were to maintain your current travel patterns after CBCP policy implementation, how much of a monthly congestion toll budget would you need to pay the tolls? (Assuming peak-period tolls are 25 cents per mile on all congested roads)
Take the number of miles you travel a day on 'stop and go' roadways. This mileage/day_____ x $0.25/mile x 30 days/month = $_______of congestion toll budget.

12) How reasonable would a $50.00 monthly budget be for meeting an average Dallas resident's travel needs? It would be

☐ way too much
☐ more than required
☐ about right
☐ less than required
☐ way too little

13) Imagine that a CBCP policy is implemented in your city, and that three types of travel budgets are given to licensed drivers: High (for example, $75.00 per month), Standard (say $50.00), and Low (say $25.00). People commuting to work every day get the Standard budget. Which budget type do you think each of the following user groups should receive?

	High	Standard	Low	No budget
High school students	☐	☐	☐	☐
College/university students	☐	☐	☐	☐
Unemployed persons & retirees	☐	☐	☐	☐
Long-distance commuters (driving more than 25 miles each way)	☐	☐	☐	☐
Low-income workers	☐	☐	☐	☐
Unemployed parents of small children	☐	☐	☐	☐
Others: ___________________ (please specify)	☐	☐	☐	☐

14) How much, do you think, should each budget category consist of?
High: ___________ dollars
Standard: ________ dollars
Low: ____________dollars

15) As mentioned, a CBCP policy involves redistributing congestion toll revenues to drivers in the form of travel budgets. Whom do you think should receive such travel budgets?

- All drivers
- Only low-income drivers with special travel needs (for work, health or education), so that the remaining revenues can be used for transportation improvements in the region

16) In order to prevent fraudulent representation of one's place of residence (in order to obtain travel credits), do you think it is reasonable to provide travel budgets only for use of vehicles registered (and insured) in the region of CBCP application, rather than to all licensed drivers?

- Yes
- No

17) Following are potential factors that could be used to determine a driver's monthly travel budget. Please order them from 1 to 5 with 1 being the most appropriate factor to use and 5 being the least appropriate.

Current use of congested roads during rush hours
Purpose of travel during rush hour
Current level of travel overall
Distance between work and residence
Household income
Work flexibility or schedule
Child care or other special needs
Availability of transit or ride share alternatives

18) If a CBCP policy were implemented, would you be willing to share your credit card information to facilitate payment? (Note: One may pay for TollTag/transponder transactions with cash or check.) I would be willing to share such information

- ☐ only with a government agency.
- ☐ only with a non-government agency.
- ☐ with whatever company was managing the system, whether or not it was a governmental agency.
- ☐ No; I would not share my credit card information with any system manager.

19) If a CBCP policy was implemented first on all Dallas area highways within the outer loop (820-20-635-183), how would you prefer toll rates to be set?

- ☐ As a flat rate during peak-hours
- ☐ As a variable rate, based on level of congestion

20) If a CBCP policy was implemented on all highways leading in and out of central city areas (IH 35E, IH 45, US 175, IH 30, US 75, IH 35W, SH121) how would you prefer the toll rates to be set?

- ☐ Based on direction and time of day, (inbound lanes charged in the morning, outbound in the evening)
- ☐ Same toll rates for both directions on a highway

21) Please indicate your level of agreement with the following statements. Do not check if you have a neutral opinion.

A policy of CBCP would…

	Strongly Agree	Agree	Disagree	Strongly Disagree
…reduce peak-hour congestion				
…redistribute traffic across modes and routes				
…result in spreading the peak-hours				
…result in higher transit use				
…encourage poorer drivers to stay off the roads during peak-hours				
…inflate centrally located land values				
…be difficult to implement				
…congest minor roads and frontage roads				
…intrude on privacy				
…result in people fraudulently using the system to make money				
…ensure efficient roadway use				
…ensure everyone has equal access to the highway network				
…benefit the local economy				

22a) Where would you like to see CBCP revenues spent?

- Only along the corridor where tolls were collected
- Only in the region where tolls were collected
- Any region of Texas, where most needed

22b) How would you like to see CBCP revenues spent?

- Only on transportation-enhancing projects
- For any public need, as appropriate (e.g., education, parks, policing)

22c)If some portion of CBCP revenues were to be spent on transportation projects, how would you recommend these be invested?

- Invested only in expansion of existing roadways and construction of new roadways
- Invested in expansion, construction, and maintenance of roadways
- Invested in roadways and other transportation modes (e.g., DART and buses)

23) Which of these policies do you **strongly support for congestion control** in DFW? (Check all that apply & please note that almost all the options will require direct or indirect taxation.)

☐ More buses &/or rail, funded by local & federal taxes and user fees
☐ More roads; new location or widening of existing roads funded by state and federal gas taxes
☐ Flat (constant-rate) tolls
☐ Variable congestion tolls (dependent on traffic conditions and/or time of day)
☐ Credit-based congestion tolls (where toll revenues are returned in the form of travel budgets)
☐ More HOV/HOT lanes (HOV = high-occupancy vehicle, HOT = HOV or single-occupancy vehicle paying toll)
☐ Higher parking charges
☐ Other policies (please specify):_____________________

General Questions:

24a) How many people live in your household? (Include yourself, also include roommates, even if they are not related to you.)

____ person(s)

24b) Of those living in your household, how many are licensed drivers? (Please include yourself and teenage drivers.)

____ licensed driver(s)

25) How many vehicles does your household use daily or almost daily? (Include cars, trucks, vans, SUVs, motorcycles and work-related vehicles.)

_____ vehicle(s)

26) What is your age?

_______ years

27) Your gender:

☐ Female
☐ Male

28) If you have children living with you, how many are in the following age groups?

Below 3 years of age: _______ children

Between 3 and 15 years of age: ________ children

29) What is your **home address**? (Note: Please feel free to report the address to the nearest 100. For example, 1618 Meadowbrook St. can be given as 1600 Meadowbrook St.)

____

30) What is your **workplace/school address**? (Again, please feel free to report the street address to the nearest 100.)

____

31) What is your **household's** approximate **annual income (before taxes)**? (Please note that all information will be kept highly confidential. Income is a key variable for our predictions of travel behavior, since it influences time-money tradeoffs.)

- ☐ Under $10,000 (household yearly income)
- ☐ $10,000-$24,999
- ☐ $25,000-$34,999
- ☐ $35,000-$49,999
- ☐ $50,000-$74,999
- ☐ $75,000-$99,999
- ☐ Over $100,000

32) What is the highest level of education you have completed?

- ☐ Less than high school
- ☐ High school (or equivalent)
- ☐ Associate's or technical degree (or equivalent)
- ☐ Bachelor's degree
- ☐ Master's degree or higher

33) Please use this space for your questions, suggestions, and comments related to a CBCP or other, similar policy. We want to hear from you!

____
____
____

If you would not mind our contacting you again, for additional feedback on transport policy in the DFW region, please provide us with your email address or home street address: ____________

Appendix B1: CBCP Policy as Described to Survey Respondents

The proposed policy provides every licensed driver in a region a travel budget to spend on congestion tolls, via a toll tag account linked to his/her name. Marginal-cost pricing for delays induced by added roadway users would be imposed on all major, congested roads, thus providing monthly travel budgets estimated to be on the order of $20.00 to $50.00 in the Austin and DFW regions. Any budget not spent by the end of the month's time serves as a cash savings or credit to the account holder. Those exceeding their budgets, however, would have to pay for additional tolls out of pocket. The policy is meant to be revenue-neutral in that all revenues collected each month are distributed among all qualifying drivers in the region. Essentially, those who wish to drive during congested periods pay others to stay off those roads at those times. Digital signs over the roadways would indicate costs per mile or section of road and vary by time of day. CBCP can be implemented via Electronic Toll Collection (ETC) and Dynamic Pricing, so that tolls vary with congestion levels.

Appendix B2: Survey Questions: Transport Economists

1) While a CBCP approach offers some clear equity benefits (since those who economize, by carpooling or taking transit, for example, can actually "make money"), do you foresee any serious problems of equity? Do you feel almost everyone would have a reasonable level of access to the highway network? Can you imagine reasonable solutions to any equity issues that may arise (e.g., offering extra travel budget allowances to welfare-to-work participants and heads of single-parent households)?
2) Do you think CBCP is an economically efficient and maximally effective strategy? What modifications would you implement to make CBCP more efficient and effective?
3) What do you find most attractive about a CBCP policy?
4) Under a CBCP policy, what land use changes might you expect for a reasonably congested region in the U.S.?
5) Do you think CBCP could impact local and/or state economies? What short-term and longer-term changes would you anticipate?
6) Considering that many states are looking at tolls as a way of financing infrastructure, it may be practical to collect infrastructure tolls and congestion tolls together. If this were to be implemented, would this marginalize the effect of a CBCP policy or congestion toll?
7) Please rank your concerns about CBCP, with 1 being the most important. Feel free to write additional comments about other concerns that you may have.
    a. Privacy [ ]
    b. Administrative burdens [ ]
    c. Technological viability [ ]
    d. Giving the same travel budget to all (Irrespective of work status, income, etc.) [ ]
    e. Efficiency [ ]
    f. Other(s):____ [ ]
8) If not all revenue were to be returned to travelers, how would you recommend such monies be used in your city/region? Please rank the following alternatives. (1 being the highest)
    a. Building new infrastructure [ ]
    b. Maintaining existing infrastructure [ ]
    c. Subsidizing travel alternatives or improving transit [ ]
    d. Reduction in gas taxes [ ]
    e. Addressing air quality [ ]
    f. Other(s):____[ ]
9) Would you advocate any other congestion management policy other than CBCP for implementation in your city? Why?
10) Do you have any specific questions or suggestions about CBCP?
11) Are you willing to be contacted in the future for more detailed discussions of the strategy?

Appendix B3: Survey Questions: Toll Technologists

1) What technology do you recommend for application of CBCP? (For example, RF tags, GPS units)(Note: While there will be only one account per driver, larger vehicles, such as trucks and limos, may be charged more, given their added delay impacts; so vehicle ID tags also may be needed.)
2) Would you recommend a large capital investment in toll technology, or do you feel current toll technology will be obsolete in only a few years and such expenditures may be unwise at this time?
3) In applying charges (per mile or per section of roadway), what basic toll configuration would you recommend: should roadside detectors be placed at one-mile intervals, or at entrance and exits to the freeway? What other basic configuration would you recommend?
4) How much would such a technology cost? Please give your cost estimate per toll station, per lane-mile or per mile (if number of lanes is immaterial).
5) What type of equipment would you recommend on-board each vehicle? How much would such a device cost if distributed to at least 100,000 users?
6) Do you think enforcement will be a problem? What kind of technology do you recommend for violator detection and identification?
7) How many units of such enforcement technology are needed per toll station, and how much does each unit cost?
8) At what maximum frequency and maximum charge per mile do you recommend changing the congestion toll on links with variable traffic levels (e.g., every 15 minutes at no more than 10¢ per mile traveled)?
9) Where should message-boards best be installed? And what types of messages should be displayed?
10) What might be the best way to handle complaints? (For example, complaints by persons who feel wrongly charged.)
11) What information would you recommend keeping for accounting or other important purposes under a CBCP policy? (E.g., Toll tag number plus name, address, social security number, credit card information, vehicle registrations, speeding violations, and/or other information related to account holder.)
12) How should *visitors* to the system be charged? (Many may come from out of the region and will not have a recognized transponder.) Please rank the following alternatives. (1 being the highest)
    a. Rent on board units [ ]
    b. Charge the visitor an appropriate toll (in cash) [ ]
    c. Allow to drive for free if minimal use [ ]
    d. Other:________________________________ [ ]
13) What do you like best about the CBCP policy we propose? And, what are your concerns?

14) Do you have any specific questions or suggestions for application of a CBCP policy?
15) If we have further questions, may we please contact you in the future?

Appendix B4: Survey Questions: Administrators and Policy Makers[19]

1) What administrative issues do you foresee if a CBCP strategy were implemented on your city's/region's highways? What amount of record keeping do you foresee for such a policy? Would there be any specific records that should not be kept on file in order to maintain additional privacy? (e.g. credit card numbers, social security numbers, name, vehicle type, license plate) Would you recommend third-party account distributors to reduce privacy concerns?
2) Would you anticipate any legal impediments to implementing a CBCP strategy? In addition, do you anticipate any problems with enforcing this policy?
3) As a policy-maker, what would be your primary concerns if a CBCP strategy were to be implemented? What would be the primary concerns of your constituents? (For example, privacy, administrative burdens, and/or technological feasibility.)
4) What do you find most attractive about a CBCP policy?
5) What do you find least desirable about such a policy?
6) What problems of equity do you see in a CBCP policy? Do you feel everyone would have adequate/reasonable access to the tolled network, regardless of income?
7) Would a revenue neutral-policy be infeasible for any reason (in regards to the eventual return of all money collected by the CBCP system, minus administrative costs)?
8) If revenue is generated, do you anticipate any issues regarding splitting the revenue between local, state and federal governments, since different roads are managed by different agencies?
9) How important is public support for implementation of this policy? Do you feel that people will support CBCP?
10) Considering that many states are looking at tolls as a way of financing infrastructure, it may be practical to collect infrastructure tolls and congestion tolls together. Would you recommend this joint strategy?
11) Under a CBCP policy for the Dallas-Ft. Worth region, where should the geographic cut-off be for regular users of the DFW freeway system? Who would be classified as residents (with the right to acquire a transponder) and who would be classified as guests (having to prepay into the system with each trip on a freeway during congested times)?
12) Assuming that congestion pricing revenues (in excess of administration costs) are to be allocated among residents with driver's licenses in the region, how should the revenue be allocated? Should it be allocated uniformly? Or based on age, number of dependents, work status (e.g. student, retired, and full-time versus part-time employees) and/or other factors? If yes, then how?
13) What *exceptions* should be made for a CBCP policy? Are there any users of the system who should be partially or fully exempted from congestion pricing charges? If so, who are these users and/or what vehicles do they drive? (For examples, buses, postal service vehicles,

[19] The respondents did not explicitly answer the questions. However, their responses have been split up so as to be in the form of answers to the questionnaire.

police cars, emergency vehicles, and other public services, taxi cabs, persons with disabilities, welfare to work participants.)

14) If you are familiar with freeway corridors in Austin and/or the Dallas-Ft. Worth region, please circle which of the following freeways you feel would be the best candidates for such a policy and please note why.
Austin: I-35, Loop 1 (Mopac), Highway 71 (Ben-White), US-13, SH-130, US-290

Dallas: Northwest Irving/DFW corridor, I-30, IH-820, LP-288, US-67, IH-20, US-287, IH-820, LP-12, SH-183, US-187

15) Would you advocate any congestion management policy *other than* CBCP for implementation in your city/region? If so, why?

16) Do you have any specific questions or suggestions about CBCP?

17) Are you willing to be contacted in the future for more detailed discussions of the strategy?

Appendix B5: Survey Questions: Commercial Users[20]

1) As a commercial user of the freeway system, what would be your primary concerns if a CBCP strategy were to be implemented? (For example, privacy, administrative burdens, and/or technological feasibility)
2) What limitations do you see with such a policy?
3) What do you find most attractive about a CBCP policy?
4) How dependent is your organization's profits on travel times/costs?
5) What changes in employment would you make under a CBCP policy? Would you pay for your employees' congestion tolls incurred on their way to/from work? Would you be willing to change your work schedule? (Please note that the congestion toll paid might be compensated by the travel time savings and increased reliability).
6) If CBCP is implemented in your city, with all the freeways being charged, would you consider relocating your organization? If so, which locations would you prefer? (away/towards priced corridors, closer/further away from the Central Business District)
7) What problems of equity do you see in a CBCP policy? Do you feel everyone would have adequate/reasonable access to the highway tolled network, regardless of income?
8) If not all revenue were to be returned to travelers, how would you recommend such monies be used in your city/region? Please rank the following alternatives. (1 being the highest)
   a. Building new infrastructure [ ]
   b. Maintaining existing infrastructure [ ]
   c. Subsidizing travel alternatives or improving transit [ ]
   d. Reduction/rebate in gas taxes/property taxes [ ]
   e. Addressing air quality [ ]
   f. Other(s):___________________________________ [ ]
9) Under a CBCP policy for the Dallas-Ft. Worth region, where should the geographic cut-off be for regular users of the DFW freeway system? Who would be classified as residents (with the right to acquire a transponder) and who would be classified as guests (having to prepay into the system with each trip on a freeway during congested times)?
10) Assuming that congestion pricing revenues (in excess of administration costs) are to be allocated among residents with drivers' licenses in the region, how should the revenue be allocated? Should it be allocated uniformly? Or based on age, number of dependents, work status (e.g. student, retired, and full-time versus part-time employees) and/or other factors? If yes, then how?
11) If you are familiar with freeway corridors in Austin and/or the Dallas-Ft. Worth region, please circle which of the following freeways you feel would be the best candidates for such a policy and please note why.

[20] The respondents did not explicitly answer the questions. However, their responses have been split up so as to be in the form of answers to the questionnaire. The responses have been tabulated in Appendix D.

Austin: I-35, Loop 1 (Mopac), Highway 71 (Ben-White), US-13, SH-130, US-290

Dallas: Northwest Irving/DFW corridor, I-30, IH-820, LP-288. US-67, IH-20, US-287, IH-820, LP-12, SH-183, US-187

12) Would you advocate any other congestion management policy other than CBCP for implementation in your city/region? If so, why?

13) Do you have any specific questions or suggestions about CBCP?

14) Are you willing to be contacted in the future for more detailed discussions of the strategy?

Appendix B6: Responses of Transport Economists

1) While a CBCP approach offers some clear equity benefits (since those who economize, by carpooling or taking transit, for example, can actually "make money"), do you foresee any serious problems of equity? Do you feel most everyone would have a reasonable level of access to the highway network? Can you imagine reasonable solutions to any equity issues that may arise (e.g., offering extra travel budget allowances to welfare-to-work participants and heads of single-parent households)?

"The questions that I have are these:

1. If I never use the freeways to commute, do I still benefit? If not, should I also get the same subsidy as those who do need to use a congested freeway to get to work?
2. If my employer requires me to punch-in at 8:00 AM for a $10.00 per hour job, which may not be a welfare wage job, I likely would not benefit and probably would have to pay. I would say it is not fair.
3. The opportunity for fraud would be significant such as verifying wages, tampering with the toll tag, etc." **[Abigail McKenzie, Director of Economic Analysis and Ken Buckeye, Minnesota Department of Transportation]**

"Perhaps I just don't understand this, but if $ is first charged to all folks, then given back to 'good' drivers (defined as off-peak users), this is an imposed tax that citizens, particularly Texans, would recoil at. People have to travel when their schedules require, particularly for work, drop off kids, etc. If it means that people would be 'stopped' en-route and denied access if they were over the limit, unless they paid more, then a firestorm will ensue. People will see this as hugely oppressive and heavy-handed. Why should government say whose trips are efficient and whose not? This is also very 'big brother' and privacy invading.

(*Do you feel most everyone would have reasonable level of access to the highway network?)* NO, would cause huge inequities at the time of imposition.

(Can you imagine reasonable solutions to any equity issues that may arise (e.g., offering extra travel budget allowances to welfare-to-work participants and heads of single-parent households)?) Not at the time of imposition. And to figure it out later would be a nightmare pitting every whining group in the region against one another and the agency foolish enough to do this." **[Dr. David Hartgen, Professor of Transportation Studies, University of North Carolina at Charlotte]**

"There are always problems of equity (regardless of the alternative, including the status quo). In the proposed case, those who have the least alternative to switch departure times will pay more while those who can easily switch will pay less. This may or may not correlate with income classes (thought that is empirically testable), or spatially (which is again testable). (It would make a nice paper: departure time vs. income & origin and workplace locations). It likely hurts those with jobs with no departure time flexibility, and peak work times (e.g. more likely it hurts office workers than factory workers or hospital workers, since the latter jobs are shift based, and shifts tend to be off-peak).

People who have a license (or a car) but don't drive still automatically get credits. If credits are customized per person, that isn't fair either, and requires constantly updating and a large bureaucracy to maintain.

Another question, is the toll plan ubiquitous (like say London), or facility-specific, (which is implied by ETC)? If the latter, other problems of people rerouting to avoid tolls may occur, making the freeways less congested (or even uncongested, wasting capacity), while surface streets become more congested. Previously uncongested roads might become congested if other roads are tolled. I trust this can be dealt with, but this requires more roads than are congested now.

Additional budget allowances for some class of people is likely to be seen as unfair as well, and will make the program seem more like a welfare program. Welfare should be taken care of in a separate program (in my opinion, negative income taxes, but at any rate, it shouldn't be conflated with transportation policy)." **[Dr. David Levinson, Assistant Professor, University of Minnesota]**

"You have 2 programs merged into one: an income transfer (equity) and a pricing improvement (efficiency). The income transfer is a grant of "rights" to drivers for some amount of peak period highway travel, but this is (since it can be converted to cash) simply window dressing; each driver receives $20.00 -$50.00 each month.

Such a lump-sum transfer is always favorable from a vertical equity standpoint, over some income range. In this case, "drivers" are the targeted group. Since non-"drivers" will also want to receive the grant, a strong incentive is created for everyone to become a "driver." From the standpoint of social reward, there is no reason to particularly favor motor vehicle owners. Thus the optimal policy on vertical equity grounds is a cash grant to everyone, without regard for age, disability, or other circumstances. Because car owners are generally more affluent than the average, vertical equity is improved by including non-drivers (i.e., everyone else) in the program. A grant of this sort is the opposite of a "poll tax" in which everyone PAYS the same amount, about as regressive as possible without actually charging more to people with low income. Social engineering (awarding larger grants for socially preferred behaviors) is not desirable, nor necessary." **[Dr. Douglass B. Lee Jr., Principal Investigator, Volpe National Transportation System DTS-42, US DOT]**

"I see no "equity" issue in requiring people to pay the costs arising out of their journeys" **[Gabriel Roth, Civil Engineer and Transport Economist, Chevy Chase]**

"The main equity issue that I see is the cost-versus-means problem: how do you avoid making the system regressive? Would lower income in general qualify one for a higher travel budget? And how would you verify income? You mentioned some special cases in the question, which seem reasonable. But the general case of low versus high income seems equally problematic. The administrative burden of verifying who should get what seems like it could be quite high to achieve the flexibility that you would want.

Another issue is this: if all major congested roadways are tolled, how would a poor driver avoid being priced out of working in a congested location, assuming that there were no untolled roadways that provided the needed access? Transit is a solution that currently works for only limited trip pairs." **[Dr. Guillaume Shearin, Principal Transportation Planner, Parsons Transportation Group, Inc.]**

"No (equity problems). Yes (everyone would have access to the highway network).
(Can you imagine reasonable solutions to any equity issues that may arise (e.g., offering extra travel budget allowances to welfare-to-work participants and heads of single-parent households)?)

(a) The examples provided may be reasonable, provided eligible users are not completely held harmless.

(b) My assumption from your description is that only freeway-level facilities would be charged, leaving surface streets uncharged. This should be considered in the design of any equity-improvement scheme.

(c) The monthly travel budgets are provided gratis. This should go a long ways towards addressing this issue." **[Jack Svadlenak, Transportation Economist, Oregon Dept. of Transportation]**

"Clearly CBCP goes a considerable distance toward resolving the equity issues raised by concerns about "Lexus Lanes." It does not resolve those concerns entirely, because many will argue that lower income people are particularly dependent upon highway transportation. In view of the standard theories about housing price gradients, many will argue that lower-income people can only afford the lower housing prices at some distance from Central Business Districts and other centers where jobs are located, thus making them more dependent upon low-cost highway transportation. While CBCP is less inequitable than simple toll lanes, they would argue, it still is potentially inequitable. On the other hand, it is difficult to say at what level a subsidy could be set that would cure the system of inequity against those with low incomes who must commute considerable distances to work without unduly subsidizing those who have normal incomes but simply choose to live a considerable distance from work.

I think the bottom line on this issue is that the transportation system is an inefficient mechanism for redistributing incomes. If we believe that we should redistribute incomes, we should do that more directly in the labor market, through minimum wages, encouragements to unionization, and low-income tax credits. While extra travel budgets for welfare-to-work participants might be desirable, they should be provided through the welfare-to-work program, not through the CBCP program." **[Jack Wells, Chief Economist, Bureau of Transportation Statistics]**

"I think that this plan can increase both horizontal and vertical equity (see http://www.vtpi.org/equity.pdf). The road system is a public resource, built with public funds on public land. This type of allocation is fairer than the existing "first come" basis, and it could benefit lower-income people. I think that the overall equity impacts will depend significantly on whether credits are allocated per capita, per adult, per driver or per registered vehicle. Per capita or per adult will tend to benefit disadvantaged people most, while per vehicle will benefit the wealthy most, and will provide a perverse incentive for people to purchase multiple vehicles so they will have more credits.

There are sure to be debates about equity: most people seem to assume that existing allocations are fair, and any change is unfair, unless it makes them better off. Many people will claim that they "need" to drive during peak hours, and that this will be a financial burden, but such claims are often false, either they CAN use alternatives, such as shifting time, mode or destination, or it is possible to demonstrate that the net benefits (reduced congestion delays and vehicle costs) are worth their incremental costs." **[Todd Litman, Transport Economist and Director, Victoria Transport Policy Institute]**

"(*While a CBCP approach offers some clear equity benefits (since those who economize, by carpooling or taking transit, for example, can actually "make money"), do you foresee any serious problems of equity?)*

Yes! If you give an account to every licensed driver you will be providing a subsidy that has no particular equity benefit. For example, high school students who are licensed drivers would appear to have little reason to drive on congested roads at peak times, but they would get an account. The redistribution would make little sense.

(Do you feel most everyone would have reasonable level of access to the highway network?)

No matter how you do it, you are going to be placing a financial burden on some people. Nevertheless, I think the arguments about the equity impact are substantially overstated.

(Can you imagine reasonable solutions to any equity issues that may arise (e.g., offering extra travel budget allowances to welfare-to-work participants and heads of single-parent households)?)

Yes, but they all involve administrative cost and possible perverse incentives." **[Dr. Anthony M. Rufolo, Professor, Portland State University]**

"The proposed approach could clearly address equity concerns about congestion pricing. You might want to refer to Patrick DeCorla Souza's FAIR lanes proposal as an application of what you are seeking to do. Patrick may also be a good source on the pros and cons of your approach. The biggest challenges for this approach are political and institutional." **[Dr. Lee W. Munnich, Jr, Senior Fellow and Director, State and Local Policy Program, Humprey Institute of Public Affairs, University of Minnesota]**

"a) One line of attack could come from citizens who own no automobile, or who currently prefer to use public transportation. The funds that are expended to purchase and distribute transponders, enforce use of the transponders, install tag readers where needed, and administer the program might have been expended to upgrade transit facilities or transit vehicles.

b) The unequal value of time among motorists remains an equity issue. For drivers to whom time is relatively cheap, the option of paying a toll is inferior to the option of driving on a congested highway. The option of not traveling during congested hours may also be inferior, even with compensation. The late William Vickrey, out of deference those whom he called “the hard-core unanimists”, suggested once that a holding area be built at each checkpoint (i.e., each tollgate or each tag reader) on a tolled facility. At each checkpoint drivers would have the option of paying the toll, or of parking in the holding area for a length of time equal to the delay they would experience if the toll were not imposed!” **[Jim Gillespie, Virginia Transportation Research Council]**

“Whether specific equity issues arise will depend on local circumstances. In general, the instrument of distribution of credits adds a degree of freedom to the government to pursue equity goals (if relevant), so there appears to be no fundamental problem.” **[Dr. Erik Verhoef, Professor, Department of Spatial Economics, Free University, Amsterdam]**

2) Do you think CBCP is an economically efficient and maximally effective strategy? What modifications would you implement to make CBCP more efficient and effective?

“I’m not sure it is really economically efficient: Efficiency is the “condition that exists when resources are allocated so that no activity can be increased without reducing another”. While the payment gives a price signal to consumers about driving, by actually “paying” folks to car pool or avoid the peak, you may be suggesting the price during the peak is actually higher than the efficient level. In addition while this approach has a demand side effect, it does not have a supply side effect. For efficient allocation of resources the higher prices should result in a price effect for the supplier as well. Administrative costs of the program would also reduce its efficiency.” **[McKenzie and Buckeye]**

“NO. Road systems are not intended to be internally 'optimal' but provide access to sites for provision of benefits in non-road life. The central error of most 'transportation economics' thinking is that the 'road system economics' should somehow 'close' and be 'efficient', thus missing its purpose to most people.
Who (what agency) would actually do this? The DMV (yikes), the DOT, the toll agency, a new agency?” **[Hartgen]**

“There are two policies: One is congestion pricing, which depending on how it is implemented may be very efficient (assuming low administrative costs).
The second is credits to drivers, which is an income transfer. This is not especially efficient, and may be seen as creeping socialism or welfare, or something else (especially if the credits are income based).

Another strategy (I don't know if it is better, but it may be perceived differently) would be to set it up on the income tax form ... the first $Y paid per year (say up to $500.00 the number would depend on typical payments etc.), would be a credit off total state income taxes paid. So if you would have had $5000.00 in state income taxes (I don't know how this works in Texas now, but in MN we have state income tax), and you spent $500.00 in credits, you would only actually pay $4500.00. If you paid $600.00, you would still pay $4500.00. If you only spent $450.00 on tolls, you would pay $4550.00 in taxes.. Thus there is an incentive not to drive during peak for everyone immediately (the tolls are out-of-pocket, the refund is deferred), and it hits people who drive a lot during peak most, but doesn't give more in credits that you actually use. So people who have a license but don't drive don't automatically get credits. This last I think is a major perception problem with the current scheme. You may be able to change the current scheme so that you get credits for the first $Z/month you spend, but not more than you spend." **[Levinson]**

"I have downloaded the papers and read portions of them, but I may have missed some of the details. I perceive, however, some confusion about congestion pricing (CP) versus "financing infrastructure." If you charge marginal cost, then p = MC. If the road is already tolled, the tolls are included in the price. Same with the gas tax. If congestion pricing yields some surplus over current charges (as it will in urban areas during peak periods, at least in the peak direction), then that surplus can be rebated according to CBCP. Whether that surplus averages $20.00-$50.00 per driver (yet alone per person) per month requires some investigation. At $20.00 for drivers, I get about $35 billion a year, not sky-high; at $50.00 for the population as a whole, it's closer to $200 billion. This is quite a bit of money sloshing around, for gains I suspect are perhaps less than 10 percent of the revenues, especially at the upper end (i.e., maximal equity).
So if you are preserving existing financing instruments, CBCP cannot rebate all the revenues. Because drivers are already paying too little relative to long run costs, there will still be too much road travel. If CBCP prices ignore existing instruments but maintain them, you will be charging too much in many situations. If you reduce or eliminate existing instruments, then you have no way to finance either expansion or maintenance of the highways." **[Lee]**

"Charging marginal costs is economically efficient. The program would be more efficient if surplus revenues were used to attract appropriate funding to efficient expansion of the congested facilities, as in a market economy." **[Roth]**

"The answer to this question depends on how you set the travel budgets and road prices. I think it could be an economically efficient scheme if everyone had the incentive to conserve on their driving in peak-period conditions, depending on how high the administrative costs become. Effectiveness would likewise depend on the relative relationship of prices and travel budgets. Of course, given the absolute mess of the current system, even a modest step toward efficiency and effectiveness would be welcome, so I don't think that efficiency and effectiveness are the most important issues. I think the equity and related political issues are more important." **[Shearin]**

"*(Do you think CBCP is an economically efficient and maximally effective strategy?)*
Economically yes; in a practical sense, no.
(What modifications would you implement to make CBCP more efficient and effective?)
First, consider the inter-relationship between the freeway system and the "surface street" system. If there is a lot of substitutability/diversion there, you may want to consider ways to price surface streets as well (we've been working on one here, give me a call if you are interested). Substitutability will lead to major traffic, livability, air quality, and land use issues.
Second, avoid dynamic pricing of the entire freeway system. Dynamic pricing works for the occasional special-case facility, but will not be accepted by the public on a <u>system wide</u> basis. Such a system would mean that none of us would know how much it will cost to get to work in the morning and how much it will cost to get home in the evening. Would you

patronize a movie theater that operated this way? (On this one, it's time for some planners and economists to climb down out of their ivory towers and inter-marry with the rest of the population.)
Third, consider how to deal with out-of-state and out-of-area users.
Fourth, if CBCP significantly reduces peak-hour travel, who pays-off all the credits (rhetorical question)? The financial structure of the policy needs to be based on projected traffic patterns, not existing traffic patterns. And those projections had better be good!
Finally, consider retaining some of the revenue to fix capacity problems that remain after pricing is implemented." **[Svadlenak]**

"No policy is ever "maximally" effective. Some policies are better than others. We normally don't have the option of seeking global optima. Local optima are usually the best we can hope for. I think CBCP is better from an equity standpoint that toll roads alone, and better from an efficiency standpoint than free highways (or highways with tolls not variable with congestion conditions)." **[Wells]**

"Yes, I think it is a very good concept, justified on economic efficiency grounds. My main suggestion is that credits be allocated per capita or per adult, not per vehicle, to insure that there is no incentive to purchase more vehicles in order to collect more credits. Also, I think that it needs to be implemented with improvements to alternative modes (cycling, ridesharing, transit and flextime), since the better the alternatives the less incremental cost travelers bear when reducing their peak-period travel." **[Litman]**

"No! Reducing gas taxes or finding some other way to substitute the congestion charges for various road use taxes would make more sense. The administrative and enforcement costs would likely be very high. Electronic tolling has drawbacks either in terms of coverage or cost." **[Rufolo]**

"I assume this could be done in an efficient and effective manner, though I suspect the public would not easily support this approach." **[Munnich]**

"I worry about the administrative cost of CBCP" **[Gillespie]**

"Not maximal: there is less scope for reducing distortive other taxes compared to standard congestion charges – or a larger need to use these to finance road building and maintenance. But the partial equilibrium effects may nevertheless be substantial. And I believe that these are likely to increase when the credits are made tradable among individuals, as we proposed in a study on similar ideas. (Verhoef, E.T., P. Nijkamp and P. Rietveld (1997) "Tradeable permits: their potential in the regulation of road transport externalities" *Environment and Planning B: Planning and Design* 24B 527-548).")" **[Verhoef]**

3) What do you find most attractive about a CBCP policy?

"Drivers/users would get a price signal that would allow them to make rational decisions regarding travel times and modes – assuming the price signal is correct." **[McKenzie and Buckeye]**

"The idea that 'quasi-congestion prices' might be calculable. But that is not worth the political costs." **[Hartgen]**

"It tries to implement an approximation of efficient pricing with non-distorting flat credits." **[Levinson]**

"Because equity consequences/prejudices constitute such a big hang-up over CP, it might be possible to politically move forward by combining CP with an equity transfer. I prefer to make the income transfer an explicit part of recycling the revenues, which is already a part of the mainstream discussion, instead of introducing a new gimmick." **[Lee]**

"A neat trick to introduce road users to ETC" **[Roth]**

"It provides a potential way of compensating the "losers" who would otherwise be priced out of the system." **[Shearin]**

"(a) Using market signals (prices) to allocate scare resources (highway capacity).
(b) Reinforcing the disincentive of pricing with the incentive of paying potential users not to use major highway facilities during peak hours.
(c) Having a well thought-out answer to the use of revenue question/issue.
(d) Providing a free "travel budget" should go a long ways towards ameliorating <u>stated</u> public concerns." **[Svadlenak]**

"See answer to #2, above." **[Wells]**

"That it may be more politically feasible than other congestion pricing strategies." **[Litman]**

"Congestion pricing" **[Rufolo]**

"An attempt to incorporate congestion pricing into the transportation system." **[Munnich]**

"Naturally, CBCP's most attractive feature is prices that reflect the social cost of congestion." **[Gillespie]**

"It may enhance social acceptability" **[Verhoef]**

4) Under a CBCP policy, what land use changes might you expect for a reasonably congested region in the U.S.?

"Depending upon how it was implemented, I think consumers would have incentive to settle closer to jobs, to carpool, to reduce peak period travel, and to increase demand for transit oriented development. All of this may increase the density of residential developments and reduce sprawl." **[McKenzie and Buckeye]**

"None. The prices are too small, and the politics too painful, to induce land use change." **[Hartgen]**

"A small change, some recentralization of housing, some decentralization of employment (assuming tolls vary spatially and are higher in the core, if tolls only vary temporally, there may be very little change)" **[Levinson]**

"Increased highway charges will steepen the rent gradient, making the central city more attractive and the fringes less so. The effect is dampened if only drivers get the grants." **[Lee]**

"I would expect high-value activities to return to city centers." **[Roth]**

"In the short run, I think absolutely nothing would happen. In the long run, there is the potential for more compact development, given the burden of the travel cost being placed on the user." **[Shearin]**

"Land use change will depend on the existing urban form and how dependent that form is on freeways for regional access and mobility. Vibrant central business districts that rely upon radial freeways to bring workers and customers to them are likely to become less competitive with suburban businesses. The retail industry requires high sales volumes to be successful. Small reductions in sales (as implied by peak hour pricing on radial freeways) can have a large effect on profitability. Conversely, suburban locations would benefit from increased sales.

Workers who need to pay additional charges each day may then prefer to work in closer suburban locations. This may cause CBD labor expenses to increase to compensate; making CBD locations less competitive.

These examples ignore the benefits of having a much more efficient transportation system. Nevertheless, they illustrate the importance of carefully modeling or thinking-through the land use implications of freeway pricing. Land use change will follow transportation system change." **[Svadlenak]**

"I would expect a reduction in sprawl, as homeowners would seek to live closer to their jobs to reduce their now-higher commuting costs. Businesses would similarly find it easier to attract employees by locating closer to where people live. Those with access to transit would be more likely to use it, and those without access to transit would be more likely to demand it. Land use would be more likely to organize itself around transit than around highways." **[Wells]**

"That's a good question. I think that by itself the effects would be modest, since it improves urban-fringe location access for some (wealthier) people, and has mixed impacts for others. The main benefit could be transit, since it would increase demand for transit services and they enjoy economies of scale, and so there could be more demand for transit-oriented development, but by itself this effect would probably be modest. However, if implemented in conjunction with a major commitment to transit the effects could be significant." **[Litman]**

"There would likely be some tendency for centralization, but you cannot rule out the possibility that the congestion price will be higher for central areas and that this will induce decentralization. The biggest impact is likely to be an increase in carpooling or similar methods of travel. In the long run it should reduce the demand for new construction and capacity." **[Rufolo]**

"I have no idea." **[Munnich]**

"One-to-five year time frame: no perceptible impact on land use.
Ten-to-twenty year time frame: possibly, just possibly, a detectable impact on land use. This change tends to reduce travel on congested roads, but whether residences would cluster around centers of employment and shopping, or whether centers of employment and shopping would disperse, I can't guess." **[Gillespie]**

"This is hard to predict, and depends on the 'rules' applied in the distribution of credits. The partial impact of the charges would most probably be an increase in density/shortening of travel distances. But the partial impact of the credit distribution may run the other way." **[Verhoef]**

5) Do you think CBCP could impact local and/or state economies? What short-term and longer-term changes would you anticipate?

"While you intend for the program to be revenue neutral, if drivers respond strongly it could be a very expensive program. The cost in increased taxes could have a dampening effect on local economies. (Although the time savings should be of equal value in theory, the distributive effect could be large) While not a monetary benefit to the region, workers might be happier and more productive. If Austin can solve the congestion problem with CBCP it will become an even more attractive place to live which will once again cause population growth and then exacerbate congestion." **[McKenzie and Buckeye]**

"YES, but not the way you think. I think its effect would be to tar the local government trying this as oppressive and quasi-communist, slowing down the interest from outside. After all, a co might ask, if the locals would do this, why not other things to us? Why should we move there?" **[Hartgen]**

"Slightly, I suspect the changes are small enough that they would not show up in macro-statistics." **[Levinson]**

"Any efficiency gains will benefit the local and state economy. If transportation facilities are used more efficiently, fewer resources need to be devoted to transportation infrastructure. If highway users pay a higher share of the total costs, other modes and higher-occupancy modes will increase their share. Less highway travel will take place and more of something else will be consumed or invested in. This assumes that users pay more for their highway travel, which would be the case if the revenue surplus is large enough to pay for all the grants while still financing the system. This means a net flow from users to non-users and from peak users to off-peak users; if this is offset by financing the grants out of general revenues, then we are back where we started." **[Lee]**

"Application of market principles to roads would turn roads from money-losers to money earners. Taxes could drop, which would stimulate economies." **[Roth]**

"I would think there might be positive local and state effects, given the efficiency improvements on the highways. That is, I think the costs born by the users to make the system efficient would be less than those born in a less efficient system. This should show up in higher local and regional productivity." **[Shearin]**

"On the whole, it should make both state and local economies more efficient/productive, and more attractive places to invest capital. As change inevitably produces winners and losers, some sub-areas could become less attractive for capital investment (see #4 above)." **[Svadlenak]**

"In general, I would think that implementation of CBCP would make a community a more attractive place to live, and thus have a positive effect on local and state economies. In some cases, where a metropolitan area crosses state boundaries, CBCP might discourage development in suburban areas in one state and encourage development in adjacent urban areas across a state boundary." **[Wells]**

"Overall, it should increase overall economic efficiency and productivity, by reducing congestion and therefore commercial transportation costs, and even more if implemented with other TDM strategies which reduce other transportation costs such as road and parking facility costs, traffic accidents and pollution. However, I think that the real economic costs of congestion are often exaggerated, most congestion costs are borne by consumers not businesses, and freight delivery deals with congestion primarily by shifting when deliveries occur." **[Litman]**

"Since congestion pricing would improve economic efficiency, a region using it should see increased growth over the long run." **[Rufolo]**

"If congestion pricing is more broadly accepted as a congestion management and transportation financing tool, I believe congestion will be more tolerable and people would adjust behavior over time to more efficiently allocate transportation resources." **[Munnich]**

"CBCP might lead to more efficient financing and more efficient utilization of congested motor facilities. These are good things, but I don't think the impact on state and local economies would be noticeable." **[Gillespie]**

"Provided carefully designed, an increase in social surplus." **[Verhoef]**

6) Considering that many states are looking at tolls as a way of financing infrastructure, it may be practical to collect infrastructure tolls and congestion tolls together. If this were to be implemented, would this marginalize the effect of a CBCP policy or congestion toll?

"Yes, given your revenue neutral assumption to the program. Generally speaking, if equity investments and toll revenue bonds are sold to finance the project, investors will require that the facility be priced to maximize toll revenue. This will conflict with the CBCP policy." **[McKenzie and Buckeye]**

“Tolls are different. You get an increment of time for an increment of $, at your choosing. If you choose not, ok. Tolls are feasible in lost of situations, where this general-pricing idea would have no takers, because it hits everyone.” **[Hartgen]**

“It shouldn't. There would be a base rate, which would be assessed to all drivers, and then a variable rate, higher in the peak lower (negative?) in the off-peak. The base should replace (not supplement) the gas tax.

However, it might confuse people to introduce too many policies at once. The policy needs to avoid being too clever. Once the infrastructure is in place to collect tolls, then you can do lots of things.

My best guess is you stage it the other way around: A base rate to replace the gas tax (which would be less controversial and get the infrastructure out there), and then later raise the tolls and add "off-peak discounts", and "uncongested road discounts".” **[Levinson]**

“This is what I meant in (2) above about confusing pricing and financing. It depends what you mean, but if a road has non-CP tolls, the CP has to be set so as to make the TOTAL price equal to marginal cost. The user does not respond separately to CP tolls and financing tolls; they are all part of the price.” **[Lee]**

“I see no substantial difference between "tolls" and "congestion tolls".” **[Roth]**

“Not necessarily. It depends on how it was introduced. The gas tax amounts to a flat toll of about 2 cents per mile currently, for a fuel consumption of 25 mpg average. One could double this rate, eliminate the gas tax, and still not have much effect on the prices for congested roads.
On the other hand, it would greatly complicate explaining and selling the program, given such a dual purpose, and could be the kiss of death. The programs should be introduced separately to avoid this confusion. Otherwise, a large proportion of the travel budget could be used up for the capital funding portion of the charges, e.g., $16.00 or so per month capital charge is about $0.04 cents per mile. This charge will be highly visible and very controversial. Based on measure funding programs, the capital portion would succeed only if a careful spending program were worked out in advance and tied to both the imposition and sunset of a capital charge.” **[Shearin]**

“Conceptually, no. However, if that means that the revenue from peak hour charges on only one or two facilities is redistributed to all residents of a metropolitan area, then the behavioral effect of that redistribution would be negligible.” **[Svadlenak]**

“I don’t see any problems with combining a revenue toll (to pay for infrastructure) with a congestion toll. To the extent that you use a revenue toll, it reduces the size of the congestion toll you need in order to achieve the desired level of congestion reduction. Revenue tolls would, of course, raise equity issues, but those issues can be resolved in the context of the revenue toll, irrespective of whether it is combined with a CBCP-style congestion toll.” **[Wells]**

"The best feature of CBCP is that it may be more politically acceptable than congestion tolls, but because it raises no funds, transportation funding will need to come from another tax source. Congestion pricing is probably more economically efficient overall, but more difficult to implement politically." **[Litman]**

"No! it would be the preferred way to raise money for construction so long as there is congestion pricing." **[Rufolo]**

"It would marginalize the effect of a CBCP policy, since the policy is designed to redistribute toll revenue among drivers, as I understand it. This would defeat the purpose of using tolls to fund infrastructure. A congestion toll or variable toll system could be consistent with using the revenues to fund infrastructure." **[Munnich]**

"I think toll financing and congestion pricing are complementary. To toll an uncongested facility is not economically efficient, of course, but it might be politically feasible. I do believe that the combination of CBCP with revenue tolls would blur its logic and its impact entirely in the eyes of the traveling public." **[Gillespie]**

"I wouldn't make this distinction so sharply – as Mohring and Harwitz pointed out, the revenues from optimal congestion charges may be sufficient to finance optimal capacity." **[Verhoef]**

7) Please rank your concerns about CBCP, with 1 being the most important. Feel free to write additional comments about other concerns that you may have.

a. Privacy [5]
b. Administrative burdens [3]
c. Technological viability [4]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [1]
e. Efficiency [2]
f. Other(s):________________________ [ ]

[McKenzie and Buckeye]

a. Privacy [2]
"Another big concern. Not for a moment would I trust the government with my travel picture. It is none of their business. The government's job is to supply infrastructure using my tax $."
b. Administrative burdens [3]
"Could be a big problem. What to do about pass-thru-ers, newcomers, is it car based or person based, movers, would there be an income-rebate (ugh in spades!), and a million other questions?"
c. Technological viability [4]
"Probably feasible, but just because it is does not mean that it makes sense."
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [1]

"This is the hang-up. For God's sake, why should government impose an equal time budget on all? Are we really at the point where "all men (sic) are created equal time-budget recipients?" "

e. Efficiency [5]

"Eh. Show me how much this would 'save' whom?"

f. Other(s):____ [ ]

"Texas is a politically conservative car-owning gun-toting place. I can't imagine this being tried."

[Hartgen]

a. Privacy [4]
b. Administrative burdens [3]
c. Technological viability [5]
d. Giving the same travel budget to all (Irrespective of work status, income, etc.) [1]
e. Efficiency [2]
f. Other(s):______________________________ [ ]

"Administrative costs should not be underestimated; London seems to be spending 60 percent of collected revenue administering their system. ETC would be less ... but may lead to people rerouting to avoid tolls"

[Levinson]

a. Privacy [ ]
b. Administrative burdens [ ]
c. Technological viability [ ]
d. Giving the same travel budget to all (Irrespective of work status, income, etc.) [ ]
e. Efficiency [1]
f. Other(s): [2]

"(E)quity and efficiency consequences of giving grants only to drivers"

[Lee]

a. Privacy [5]
b. Administrative burdens [3]
c. Technological viability [4]
d. Giving the same travel budget to all (Irrespective of work status, income, etc.) [2]
e. Efficiency [1]
f. Other(s)_______________________________ [ ]

[Roth]

a. Privacy [3]
b. Administrative burdens [2]
c. Technological viability [4]
d. Giving the same travel budget to all (Irrespective of work status, income, etc.) [1]

e. Efficiency [ ]
f. Other(s):______________________________ [ ]
"See comment above on income versus budget under equity. With respect to privacy, one could not have both privacy and special treatment in this system, which is a potential problem."
[Shearin]

a. Privacy [1]
b. Administrative burdens [4]
c. Technological viability [3]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [5]
e. Efficiency [?]
f. Other(s):___Traffic & land use impacts_______ [1]

"By "Efficiency" do you mean transportation system efficiency, economic efficiency, or efficiency in meeting some other goals?"
[Svadlenak]

a. Privacy [ ]
b. Administrative burdens [3]
c. Technological viability [ ]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [1]
e. Efficiency [ ]
f. Other(s):
Not clear how you would establish the appropriate budget level [2]
[Wells]

"I am a little confused by this question. Do you mean, which of these challenges do I think is really a problem, or which of these will be perceived as a problem by the general public and therefore be an obstacle to CBCP implementation? I think that a system such as this will be quite costly to implement, costing a hundred dollars a year or more per vehicle, and so it cannot really be revenue neutral. The technology exists, but will not have 100 percent reliability, so there will be at least some complaints. It should significantly increase overall economic efficiency."
a. Privacy [3]
b. Administrative burdens [1]
c. Technological viability [2]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [ ]
e. Efficiency [ ]
f. Other(s):______________________________ [ ]
[Litman]

a. Privacy [4]

b. Administrative burdens [3]
c. Technological viability [1]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [2]
e. Efficiency [ ]
f. Other(s):_______________________________ [ ]
[Rufolo]

a. Privacy [2]
b. Administrative burdens [3]
c. Technological viability [4]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [3]
e. Efficiency [5]
f. Other(s): Political Viability___________ [1]
[Munnich]

a. Privacy [4]
b. Administrative Burden [1]
c. Technological Viability [3]
d. Giving the same travel budget to all [2]
e. Efficiency [5]
f. Other(s): ___________________________ [ ]
[Gillespie]

"Depends on whether or not the credits are tradable. If they are:
a. Privacy [4]
b. Administrative burdens [1]
c. Technological viability [2]
d. Giving the same travel budget to all
(Irrespective of work status, income, etc.) [5]
e. Efficiency [3]
f. Other(s):_______________________ [ ]"
[Verhoef]

8) If not all revenue were to be returned to travelers, how would you recommend such monies be used in your city/region? Please rank the following alternatives. (1 being the highest)

a. Building new infrastructure [3]
b. Maintaining existing infrastructure [2]
c. Subsidizing travel alternatives or improving transit [1]
d. Reduction in gas taxes [5]
e. Addressing air quality [4]
f. Other(s):______________________________________[ ]
[McKenzie and Buckeye]

a. Building new infrastructure [1]
“They think this would be done with the $. It better be.”
b. Maintaining existing infrastructure [2]
“Fuzzier. They think their gas taxes do this now.”
c. Subsidizing travel alternatives or improving transit [ ]
“Don't even propose it!”
d. Reduction in gas taxes [ ]
“How?”
e. Addressing air quality [ ]
“Nope. Cars getting cleaner is how air is getting cleaner.”
f. Other(s):_____________________________________ [ ]
“Worst idea: giving the $ to 'low-income' or other 'dersevings'”
[Hartgen]

a. Building new infrastructure [3]
b. Maintaining existing infrastructure [2]
c. Subsidizing travel alternatives or improving transit [5]
d. Reduction in gas taxes [1]
e. Addressing air quality [4]
f. Other(s):_____________________________________ [ ]
[Levinson]

a. Building new infrastructure [Ok if B>C]
b. Maintaining existing infrastructure [Ok if B>C]
c. Subsidizing travel alternatives or improving transit [Ok if B>C]
d. Reduction in gas taxes
[Not unless there are substitute user revenue sources]
e. Addressing air quality [No]
f. Other(s): Reduce general taxes [1]
[Lee]

a. Building new infrastructure [2]
b. Maintaining existing infrastructure [1]
c. Subsidizing travel alternatives or improving transit [5]
d. Reduction in gas taxes [3]
e. Addressing air quality [4]
f. Other(s):___________________________________ [ ]
[Roth]

a. Building new infrastructure [4]
b. Maintaining existing infrastructure [2]
c. Subsidizing travel alternatives or improving transit [1]
d. Reduction in gas taxes [5]
e. Addressing air quality [3]
f. Other(s):___________________________________ [ ]
[Shearin]

a. Building new infrastructure [1]
b. Maintaining existing infrastructure [3]
c. Subsidizing travel alternatives or improving transit [2]
d. Reduction in gas taxes [5]
e. Addressing air quality [4]
f. Other(s):________________________________ [ ]

[Svadlenak]

a. Building new infrastructure [2]
b. Maintaining existing infrastructure [3]
c. Subsidizing travel alternatives or improving transit [1]
d. Reduction in gas taxes [5]
e. Addressing air quality [4]
f. Other(s):________________________________ [ ]

[Wells]

a. Building new infrastructure [4]
b. Maintaining existing infrastructure [2]
c. Subsidizing travel alternatives or improving transit [1]
d. Reduction in gas taxes [ ]
e. Addressing air quality [3]
f. Other(s): Reducing other taxes [5]

"There is a strong case for using revenues to improve travel alternatives, since the better the alternatives the easier it is for travelers to shift mode, and therefore the lower the congestion fee needed to reduce traffic volumes to an optimal level. Put another way, efficient pricing requires both that consumers have viable options to choose from and prices that reflect marginal costs. If congestion prices are implemented without good ridesharing, transit and flextime options, it will simply be a tax, but if there are good alternatives, even a modest congestion fee will cause enough shift to reduce congestion for those who drive. As a result, motorists can benefit if congestion pricing revenues are used to improve alternatives (see www.vtpi.org/tdm/tdm70.htm)"

[Litman]

a. Building new infrastructure [3]
b. Maintaining existing infrastructure [2]
c. Subsidizing travel alternatives or improving transit [ ]
d. Reduction in gas taxes [1]
e. Addressing air quality [4]
f. Other(s):________________________________ [ ]

[Rufolo]

a. Building new infrastructure [1]
b. Maintaining existing infrastructure [4]
c. Subsidizing travel alternatives or improving transit [2]

d. Reduction in gas taxes [5]
e. Addressing air quality [3]
f. Other(s):______________________________ [ ]

[Munnich]

a. Building new infrastructure [2]
b. Maintaining existing infrastructure [1]
c. Subsidizing travel alternatives or improving transit [ ]
d. Reduction in gas taxes [3]
e. Addressing air quality [4]
f. Other(s): ______________________________ [ ]

[Gillespie]

a. Building new infrastructure [1]
b. Maintaining existing infrastructure [1]
   So: apply Mohring-Harwitz
c. Subsidizing travel alternatives or improving transit [ ]
d. Reduction in gas taxes [ ]
e. Addressing air quality [ ]
f. Other(s):______________________________ [ ]

[Verhoef]

9) Would you advocate any other congestion management policy other than CBCP for implementation in your city? Why?

"From our experience with the value pricing program at the national level, it appears that the concept of high occupancy (HOT) lanes has broad appeal. The public finds the notion attractive that these lanes are an option available when they really need them." **[McKenzie and Buckeye]**

"If at all, just plain tolls for new facilities, where they make sense. And of course, spend the $ we now collect for road repairs and widening, not for transit or other ideas." **[Hartgen]**

"Normal congestion pricing, managed lanes, HOT lanes & networks, and ramp meters are all good things." **[Levinson]**

"Parking pricing, because free or under-priced parking causes severe distortions in mode choice and occupancy in areas where CP would be suitable." **[Lee]**

"Total road commercialization would be my objective, and introducing HOT lanes my initial step." **[Roth]**

"FAIR lanes might have some advantages of CBCP since the concept includes both the cross payments between users as well as leaving untolled roads for those unable to afford the system." **[Shearin]**

"Yes. We are very concerned about traffic diversion from previously free freeways to surface streets. Also, we are very concerned about impacts on land use/urban form. Finally, our "preservation and maintenance first" policies mean very little revenue is available to fund capacity improvements. For these reasons, we are exploring the concept of area pricing (where a VMT fee is charged in a defined area during set peak hours).
Finally, queue-jumping at ramp meters would have the advantage of offering a new service for a charge, instead of imposing a new charge for an existing service." **[Svadlenak]**

"No. I think, for the reasons given above under ##2, 4, and 5, CBCP would be better than the other available alternatives." **[Wells]**

"I believe that congestion pricing, with revenues used to fund travel alternatives or reduce economically-harmful taxes (such as income and business taxes) is most efficient and equitable overall, but is politically difficult, and so would support CBCP if that is the most practical way to implement some form of congestion pricing." **[Litman]**

"CBCP is likely to be inefficient and expensive. Probably would need some type of GPS based system for effective regional pricing. The Puget Sound Regional Council is about to start an experiment with a GPS based system." **[Rufolo]**

"HOT lanes/HOT networks combined with bus rapid transit. Currently a more politically feasible option." **[Munnich]**

"I would give any kind of pricing policy more than a passing glance." **[Gillespie]**

"See above" **[Verhoef]**

10) Do you have any specific questions or suggestions about CBCP?

"Has there been any estimate of the technology and software needed to implement something like this? Likewise the administration of the policy will be a serious challenge." **[McKenzie and Buckeye]**

"PLEASE drop it before the Gove gets wind of it**!"** **[Hartgen]**

"See above" **[Levinson]**

"My feeling is that it is more of a distraction than a solution" **[Lee Doughlas]**

"No" **[Roth]**

"The details mentioned above are extremely important:

- How do you avoid making the system regressive?
- Would lower income in general qualify one for a higher travel budget?
- And how would you verify income?

- If all major congested roadways are tolled, how would a poor driver avoid being priced out of working in a congested location, assuming that there were no untolled roadways that provided the needed access?" **[Shearin]**

"(a) Carefully consider the inter-relationship between the freeway system and the surface street system before applying it.
(b) It would be helpful to have the public policy purpose(s) or goal(s) of CBCP spelled-out." **[Svadlenak]**

"You probably need to think more about the question of how you establish the size of the budget credit. That part does not seem well-thought-out yet, based on the write-up that you've provided." **[Wells]**

"Have you estimated the administrative costs? How do you propose to fund them?
How do you propose to address privacy concerns, particularly in a region populated by paranoid, anti-government activists? How do you propose to handle out-of-town motorists?
It would be interesting to identify the various benefits and costs, and perform a comprehensive Benefit/cost analysis. My guess is that the congestion reduction benefits will be only modestly greater than the administrative costs, assuming $50.00-$200.00 annual per vehicle expenses, and so the real net benefits will be from any reductions in parking, accidents and pollution, and transit service improvements that result, due to travelers shifting from driving to alternative modes. (Since traffic fatalities tend to increase when congestion is reduced, it is unclear whether the congestion reductions themselves will reduce total crash costs, but shifts to alternative modes probably will)." **[Litman]**

"Dynamic pricing is likely to be very problematic if you are talking about changing prices in response to congestion levels. It seems to work on I-15 because people have an option of not paying, but they are likely to resist a variable price if they do not have any choice. Hence, the price schedule would have to be set in advance, such as SR 91." **[Rufolo]**

"No" **[Munnich]**

"A state agency that both collects from and disburses to a large fraction of the adult population, rather like the State Department of Taxation, will require some FTEs. How many?" **[Gillespie]**

"Consider tradability" **[Verhoef]**

11) Are you willing to be contacted in the future for more detailed discussions of the strategy?

"Yes" **[McKenzie and Buckeye]**
"Sure" **[Hartgen]**
"Sure" **[Levinson]**
"Sure" **[Lee]**
"Only if the strategy is consistent with getting roads into the market economy." **[Roth]**
"Yes" **[Shearin]**

“Yes” **[Svadlenak]**
“Yes” **[Wells]**
“Yes” **[Litman]**
“OK” **[Rufolo]**
“Yes” **[Munnich]**
“Yeah, sure” **[Gillespie]**
“Yes” **[Verhoef]**

General Comments:

“This is a very interesting proposal, with the attraction that people easily see it is revenue neutral and therefore may be less inclined to view it as a tax increase.

My only concern is with the general equilibrium properties. It has been shown recently that road taxes can be far less efficient, or even decrease welfare, if the revenues are returned in lump-sum fashion such as this. See Parry and Bento, Scandanavian Journal of Economics, Dec. 2001, and a working paper that generalizes their model by Kurt Van Dender, my colleague at UCI.

The way to modify the proposal to handle this is to use the revenue to reduce some other tax that either taxes labor income (such as the income tax) or that raises the cost of living (such as the sales tax).” **[Dr. Kenneth Small, Department of Economics, University of California, Irvine]**

Appendix B7: Responses of Toll Technologists

1) What technology do you recommend for application of CBCP? (For example, RF tags, GPS units) (Note: While there will be only one account per driver, larger vehicles, such as trucks and limos, may be charged more, given their added delay impacts; so vehicle ID tags also may be needed.)

"(I) believe that RF ID will at a minimum be a component of this system. RFID tags or cellular would provide the method to assign the transaction to a particular individual. I also feel that GPS will play a growing role in this technology. As GPS becomes more popular and interfaces into traffic management systems it would provide an accurate means of assessing a mileage based user fee." **[James J. Eden, ACS Electronic Toll Collection]**

"Assuming a closed system (only tagged vehicles participating in the program could use the highway), toll tags should be sufficient." **[Michael Freitas, ITS Joint Program Office, ITS cell FHWA]**

"RF tags. They are readily available and much less expensive" **[John Gaynor, Director of Transportation Management Systems, Transtar, Houston]**

"CVISN technology is working well for Interstate trucking. Some form of that technology may work for CBCP. I don't think there is a technology that is directly adaptable to your policy." **[Stephen J. Bahler, ITS Program Manager, Olsson Associates]**

"The application you are describing in your policy would require the deployment and use of a large number of different technologies. These technologies would require implementation along the roadway infrastructure, traffic management center, motor vehicle department, communication links between these systems, and in the vehicles.

As a result, it is extremely difficult to identify specific technologies. A detailed study is required following a structured system engineering process to allow the local agencies to collectively select the technologies that would be most appropriate to select. The concept of operations and requirements for this system will be critical in providing the framework and detailed information to allow the technologies to be selected that are most appropriate. This would take into account issues associated with what facilities will be included in system, is automated enforcement required, how billing will be performed, what percent of driving fleet is required to have technologies installed, etc." **[Jon Obenberger, FHWA Office of Transportation Management, ITS cell FHWA]**

"Currently, DSRC transponders and automated number plate recognition (ANPR) have been the most successful technologies used for road pricing programs. In the future, all vehicles will most likely be equipped with built-in telematic devices such as transponders and/or GPS units that will enable all vehicles to be tracked or charged for some sort of toll. The current European road user charging programs for heavy vehicles have tried several technologies including DSRC transponders and a combination of GPS/cellular on-board units (OBUs). Several programs have successfully implemented the proven DSRC transponders, while the

GPS/cellular technology has not yet proven successful for the implementation of the German truck tolling program TollCollect. The London Congestion Charging Program has successfully utilized ANPR for area pricing." **[Donald L. Erwin, Jr. P.E., National Business Manager, Payment Systems, PBS&J]**

2) Would you recommend a large capital investment in toll technology, or do you feel current toll technology will be obsolete in only a few years and such expenditures may be unwise at this time?

"As we know technology is constantly changing. If you wait for the "next generation" you will never implement. Where would the cellular industry be today if the industry waited for data or broader bandwidth capabilities? I believe that the key would be to specify system that looked into the future. For instance deploy reader technology that would cover a broad spectrum of frequencies and protocols. And look at systems that are "modular" where pieces can be swapped out as technology grows." **[Eden]**

"While we expect current toll tag technology to be replaced by new technology using 5.9 GHz over time, that would not make any current toll collection systems obsolete so such a system could be used for its normal life cycle. If on the other hand, such a system is not deployed for a number of years, it will likely be more prudent to move to newer technologies. I do not think DSRC at 5.9 GHz will be commercially available for at least two years." **[Freitas]**

"It (RF tags) will NOT be obsolete in a few years." **[Gaynor]**
See my answer identified above. For example depending on the technologies selected and facilities included in the study, you may still require tolls booths. For instance is this an area wide application which relies on license plates similar to the London congestion pricing scheme?" **[Obenberger]**

"Technology is always changing, especially in these times of rapid technology development. We seem to be at a time where mature proven technologies exist such as DSRC-based AVI systems. However, these technologies may not provide all of the functionality/capability necessary for regional congestion pricing schemes. It is projected that it will be another 12-15 years before it is common for most vehicles to have either aftermarket or built-in transponder or GPS devices. New technologies have promise, but may not be mature enough to garner the necessary support for such a widespread implementation at this time" **[Erwin]**

3) In applying charges (per mile or per section of roadway), what basic toll configuration would you recommend: should roadside detectors be placed at one-mile intervals, or at entrance and exits to the freeway? What other basic configuration would you recommend?

"In a transponder based system placing readers at the on and off ramps would reduce system costs while still providing the information needed for invoicing. It could also feed traffic management systems (TMS), giving an added benefit of utilizing the transponders as probes. Placing them at closer intervals would allow a finer detail for the TMS systems but would not provide a great cost benefit." **[Eden]**

"I would assume that charging for each link between interchanges would be more than sufficient. On a limited access freeway you can't get off between interchanges so there is no point determining actual mileage. The mileage can be calculated very easily using interchanges." **[Freitas]**

"It depends on what you want to accomplish. If you want Origin and Destination Study, you need from beginning to end of a segment including ALL entrance and exit ramps. Otherwise, you can set up at intervals of say 2-4 miles (which is what we use) but you will miss some vehicles that enter or exit minor ramps in between. So the result is they get one segment unaccounted." **[Gaynor]**

"Mainline detectors would have to be used between interchanges. That is the only way to charge everyone using the roadway. One set of toll readers between each interchange would be required." **[Bahler]**

"See my answer identified above. The analysis performed based on ops concept and requirements will allow these questions to be answered based on local constraints, institutional issues, etc. A scan of other similar types of tests would give you a feel for what may be possible options to select from based on the local needs and requirements." **[Obenberger]**

"We have evaluated different tolling configurations for a DSRC-based open road tolling scenario and found that both approaches are currently in use and there are advantages and disadvantages to each.

For example, a "closed" type of system where tolling points are located at each entrance and exit would typically generate the fewest number of toll transactions that must be processed, this concept requires that two specific transactions are successful to accurately complete a trip record. If either transaction is missing or flawed, the trip record is basically lost and alternative means must be employed to estimate the customer's trip.

The "open" or "barrier" type of tolling concept where tolling points are placed at intervals along the mainline and at some entries/exits typically generates more transactions, but allows trips to be more accurately constructed even if not all the transactions are successfully completed.

Other configurations such as GPS/cellular are still under development and we are unable to adequately speak to this at present." **[Erwin]**

4) How much would such a technology cost? Please give your cost estimate per toll station, per lane-mile or per mile (if number of lanes is immaterial).

"Cost is difficult to estimate without configuring the system. For instance putting readers on a gantry over multiple lanes would cost more than installing a simpler reader at the on and off ramps." **[Eden]**

"I don't have any figures for how much the roadside systems cost." **[Freitas]**

"We recently received a quote of $10,900 to $13,800 per site, not counting traffic control, computer, power, phone or modem costs nor project management. How you set up system will greatly vary for the costs. It is safe to say the more antennas you can tie into one computer, the lower the bandwidth for the communication selected, the less lane closures needed, the costs would be less. Maintenance is another issue as we spend about $22,000 per month to maintain about 230 Automatic Vehicle Identification (AVI) readers." **[Gaynor]**

"The costs are highly variable given the general concept identified. As a result, it is not possible to identify possible costs. The best source of costs for technologies can be references through the U.S. DOT ITS Program web page where a data base of unit costs for different types of technologies is provided:
http://www.its.dot.gov/EVAL/eval.htm" **[Obenberger]**

"This really depends on the selected tolling/road charging concept and technology, and there are a number of variables to consider. We do not have cost data readily available on all of the candidate technologies. Without more project/application-specific information it would be difficult to project relevant costs." **[Erwin]**

5) What type of equipment would you recommend on-board each vehicle? How much would such a device cost if distributed to at least 100,000 users?

"If you are looking at RFID a new "sticker tag" is available and costs should be in the $5.00 to $10.00 range. The other option would to be imbedded RFID in the vehicles license plate thus providing for identification of every vehicle within that state." **[Eden]**

"I think the typical AVL tag used for toll collection is approximately $30.00-$50.00 each." **[Freitas]**

"The Harris County Toll Road Authority (HCTRA) handles this. I think they require $40.00 to set up an account with the EZ TAG Store so I think that is the value of the transponder. They use a five year battery to boast the RF signal. San Antonio tried a smaller passive transponder and it is less expensive but its range is so severely reduced so you need more readers to keep the same accuracy." **[Gaynor]**

"Not able to answer this question given information provided." **[Obenberger]**

"The price of OBUs/transponders is a significant issue when it comes to implementing a widespread road charging program. The type of program suggested by the policy may require a large number of OBUs/transponders unless ANPR is used. Most basic read-write DSRC transponders cost in the neighborhood of $30.00-$40.00 each. Additional functionality can increase the cost by as much as $30.00 more. Smartcard enabled transponder OBUs can range even higher. The GPS/cellular OBUs can cost several hundred dollars each.

The most practical short-term technical solution may be some sort of low cost transponder tag that may be less than half of the current DSRC transponder. As you are aware, TransCore who provides the transponder technology for both the Dallas and Houston areas has a new product that might be appropriate for this application.

In addition to the cost of the device, if on-board devices were mandatory for those using the roads, another significant issue would be the distribution of devices to all motorists using the road. These could be distributed at area outlets such as license plate or driver license offices. Who will pay for the devices? The state or the motorists?" **[Erwin]**

6) Do you think enforcement will be a problem? What kind of technology do you recommend for violator detection and identification?

"If not every vehicle is "tagged" there will be violations. The options for enforcement are video tolling and of a photo ID system." **[Eden]**

"Enforcement shouldn't be a problem on a closed link. Then it is the same as toll collection. If on the other hand you are mixing general vehicles and tagged vehicles (I can't imagine how or why you would in a congestion pricing mode) then "enforcement" would be difficult." **[Freitas]**

"Yes. We are going to experiment with license plate recognition on the Value Pricing Project." **[Gaynor]**

"Enforcement parameters are not defined. However, human-based enforcement would be impossible and cause more congestion. Electronic or automatic enforcement is unproven. Red light enforcement using cameras, as beneficial as that can be, is still very controversial." **[Bahler]**

"Enforcement and automated billing are critical with using any operational strategy to manage the use of any roadway facility. If you have the legislative ability, photographs of vehicles' license plates is one of the required technologies." **[Obenberger]**

"From a technology standpoint, enforcement should not be a problem. For DSRC systems, adequate violation enforcement technologies do exist. "Open Road Tolling" systems utilize violation enforcement systems that are proven to perform at satisfactory levels.

A "conventional" DSRC-based system will have an Automatic Vehicle Identification (AVI) system that detects the presence of a transponder and its location. The "toll station" will also have a set of vehicle detector devices that locate and may classify each vehicle passing through the "toll station." The "toll station" will also have a video camera system that typically captures an image of every vehicle passing the "toll station." Most images are not saved unless a vehicle is detected that does not have a corresponding transponder. In that case, the roadside computer system will trigger the video camera system to save the image of the vehicle determined to be a violator.

However, from policy and a "Concept of Operations" perspective there are issues relating to enforcement and beyond that must be addressed (if they have not already been). For example, how will visitors, infrequent users, "unbanked" or cash-only users be handled? Billing non-participants for post payment can be quite labor intensive and costly (creating more overhead costs that must come out of the revenue stream). Providing a “day pass” program for non-participants where they pay a premium to use the congested road unless they enroll in the credit-based congestion pricing program may provide adequate incentive to encourage users to participate. Those who choose not to participate, and therefore do not have an account or OBU, must be dealt-with in an acceptable manner.” **[Erwin]**

7) How many units of such enforcement technology are needed per toll station, and how much does each unit cost?

“This depends on the technology used. Some systems can capture multiple lanes while others require one per lane. Also the ability to capture commercial vehicle license plate information tractor and or tractor and trailer adds complexity and cost. Instead of fines you could charge a higher fee for a license plate billing, thus giving the option to consumers of not having a tag.” **[Eden]**

“Usually there are gates or photo enforcement at every lane of every toll plaza.” **[Freitas]**

“Don't know. This is what Bill Stockton (TTI) is looking into on the Value Pricing Project.” **[Gaynor]**

“Not able to answer this question given information provided. Reference existing literature that has been done summarizing current practices of toll facilities.” **[Obenberger]**

“Again, this depends on the selected tolling/road charging concept and technology. Usually for a conventional DSRC-based application, a set of such equipment is required for each roadway travel lane plus each shoulder. The cost of these enforcement measures would vary depending on the type, manufacturer, location, and configuration. Also included would be a roadside gantry structure, roadside computer cabinets, telecommunication system (wireless or wireline), power supply, and lightning protection. The roadside gantry structure can be very much like a typical overhead sign truss. Local prices could be provided by TxDOT, although design costs would include geotechnical and structural design.

A different type of enforcement is used for GPS satellite/cellular based road charging systems. These are used to detect vehicles without an OBU or with an OBU that is not functional. This type of system also uses mobile enforcement units mounted in an enforcement vehicle. We do not have good price information for this type of system.” **[Erwin]**

8) At what maximum frequency and maximum charge per mile do you recommend changing the congestion toll on links with variable traffic levels (e.g., every 15 minutes at no more 10¢ per mile traveled)?

“I would start by changing every 30 minutes at no more than 12¢ per mile.” **[Eden]**

“I think varying the charge every fifteen minutes is about right. If you make the frequency any longer, you aren’t keeping up with typical changes in demand. More frequent changes might result in some unusual fluctuations in price responding to minor traffic disturbances.” **[Freitas]**

“Don't know we are going to experiment with variable pricing on the Value Pricing Project. Current rate is $2.00 per trip (about 10 miles). San Diego (I 15) and Los Angeles (SR 91) have Value Pricing and charge from $0.50 to $7.00 per trip depending upon congestion. I think $7.00 is the most congested day just before Thanksgiving.” **[Gaynor]**

“This is something that would require a lot of analysis by qualified economists. A too low of a charge would not divert trips. Too high could have serious environmental justice and economic impacts on small groups.” **[Bahler]**

“Once every 15 or 30 minutes is acceptable. The key is to maintain free flow travel conditions on a facility.” **[Obenberger]**

“The recommended maximum frequency and maximum charge per mile the congestion toll would change would depend on a number of site-specific factors that must be identified and assessed through further study, i.e. market forces, customer preferences, political factors, agency preferences, etc. Other congestion pricing system business rules would provide a good starting point that could be “fine-tuned.” **[Erwin]**

9) Where should message-boards best be installed? And what types of messages should be displayed?

“At a minimum fixed signing should be installed at the beginning and end of any potential trip, with variable boards at the points of fee changes.” **[Eden]**

“At a minimum, you need to alert drivers prior to decision points i.e., approaches to interchanges. There may be unique locations where a decision point to use a reasonable alternative does not occur at the interchange (and intersection where you would turn left to head towards the variable price roadway, turn right to head to head towards the interstate, both some distance away from the intersection. In those cases drivers need information to make a decision prior to the actual roadway” **[Freitas]**

“At least one mile if no other major interchange or other major signing. If near major interchange with many other signs to compete it is not unreasonable to be 2 miles in advance. Need to allow public time to react and weave to either enter "tolled segment" or exit the freeway - this is the area where wrongly deployed signing can cause congestion.” **[Gaynor]**

“Try to avoid the use of variable message boards at all costs. The system should be designed to minimize the use of any of these devices. Again, the requirements of your system will dictate if they are needed, where and why.” **[Obenberger]**

“Human factors are very important to the success of the program. Message boards must be provided at locations that provide the customers plenty of notice prior to decision points of whether to proceed on the congested roads or divert to an alternate route. The messages must be very CLEAR and easily understandable. Motorists from outside of the local area who are very unfamiliar with the congestion charging program must be handled properly. Those who do not speak English must be considered in signage.” **[Erwin]**

10) What might be the best way to handle complaints? (For example, complaints from people who feel wrongly charged.)

“The system would at a minimum require a violations processing center. You would need to add a customer service component to this center to handle tag / read / account problems.” **[Eden]**

“I’m sure toll authorities have established such procedures for electronic toll collection.” **[Freitas]**

“This is where photo enforcement would help” **[Gaynor]**

“Complaints will be numerous. New technologies have very high reliability but drivers aren't going to like getting an unexpected bill or charge. The customer service staff will probably need to be staffed so that one customer service hour is available for each 100 drivers using the system each month.” **[Bahler]**

“The people who collect the fees. Laws, policies, procedures, and a public outreach program are required to support this type of application. See current examples where HOV lanes exist or other HOT lane applications in the country.” **[Obenberger]**

“Customer service will be very important to the success of such a program. Good public information and advanced marketing will go a long way to avoiding these types of problems” **[Erwin]**

11) What information would you recommend keeping for accounting or other important purposes under a CBCP policy? (E.g., Toll tag number plus name, address, social security number, credit card information, vehicle registrations, speeding violations, and/or other information related to account holder.)

“Tag number, customer information; name, address, phone number, credit card number for automatic account replenishment, vehicle registration information for mis-read violations.” **[Eden]**

“By definition, you need basic account information (name, address, etc.) so you can charge or credit vehicles, and you need to match the tag ID to the account information. You shouldn’t need information like SSN. In fact you don’t really need a vehicle ID unless you are concerned about tag theft. In the end you need to keep the information necessary to run the business, and no more.” **[Freitas]**

“Should ask HCTRA or North Dallas Toll Road Authority. Remember, people do not like government employees having Social Security or Credit Card numbers so may need third party to be independent when checking these numbers.” **[Gaynor]**

“The only information to collect and keep is benefits information: Has air quality improved, accidents reduced, travel time increased, etc.? Keeping records on the users is going to be a large governmental night mare and be beset with individual privacy concerns. One possible way to avoid the problem is to make a privacy option available.” **[Bahler]**

“Operational performance of each facility where tolls may be charged, when and where did traffic incidents occur, revenue per mile during different time periods, and people moved on these same facilities during these time periods. Other items will be determined based on your analysis.” **[Obenberger]**

“If customers would be required to register for an account and would be in a position to have to pay a toll for roadway use, then such information as vehicle license plate and registration information, and personal data relevant to credit card purchases would be necessary. Information relating to the use of the roads under this program would be relevant and appropriate including account status and violations history.

We don’t think there would be a need for keeping the customer’s Social Security Number (and there might be customer resistance also.)” **[Erwin]**

12) How should *visitors* to the system be charged? (Many may come from out of the region and not have a recognized transponder.) Please rank the following alternatives. (1 being the highest)

---

a. Rent on board units [1]
b. Charge the visitor an appropriate toll (in cash) [4]
c. Allow to drive for free if minimal use [3]
d. Other: <u>Pay by plate</u> [2]
[Eden]

a. Rent on board units [ ]
b. Charge the visitor an appropriate toll (in cash) [ ]
c. Allow to drive for free if minimal use [ ]
d. Other: I would assume non-participating vehicles would not use the facility. If that is intended, I would guess the simplest approach is a standard toll but that now means you have toll collectors, etc. If you don’t make the standard toll prohibitive, locals will not use the tags. **[Freitas]**

“Seems like you should be exempt if you are "passing through". Easiest is a bypass lane SR 91 uses to exempt some car pools.” **[Gaynor]**

a. Rent on board units [2]
b. Charge the visitor an appropriate toll (in cash) [2]
c. Allow to drive for free if minimal use [1]
d. Other:______________________________________ [ ]
[Bahler]

“Your analysis will need to determine this based on the needs, preferences and concerns of local stakeholders." **[Obenberger]**

“This question is a challenge, due to many considerations and factors that can only be addressed on the local/community level. In order to rank the options given above one particular situation must know the background. There is no “pat” answer.

But, there must be **clear instructions to visitors** what the program is so they can easily know what their options are regarding participation or avoidance of the road pricing program. It must also be **very convenient for the visitor** to the area to participate if they so choose or have no choice but to participate” **[Erwin]**

13) What do you like best about the CBCP policy we propose? And, what are your concerns?

“It provides a means to continue to develop and support highway infrastructure and shift traffic congestion with an incentive to drivers. Potential for public concerns on privacy issues and perception of developing a system that benefits the upper class.” **[Eden]**

“I’m not sure this has any real advantage over a program that starts everyone at zero and charges all users based on congestion levels. I think the level of incentive not to drive is the same (I can receive $30.00 for not using this road when it is congested under your plan or I can save $30.00 in tolls by not using this same road over a more traditional congestion pricing plan.) And a more traditional plan does not require lists of participants getting credits etc. You just charge everyone variable tolls.” **[Freitas]**

“CBCP has an up hill fight to get over initial negative publicity of tolling "free" roads. I know it is different idea but unfortunately I think the public and elected officials will probably tie it together, i.e., US 183. Its advantages are it gets to the root cause of congestion (too many cars traveling at the same time) by giving an economic incentive to change the time or route chosen or pay a congestion price to keep the roads flowing during peak times. It is the only plan that accounts for benefits to those that are unable to pay more by allowing credits if most of the travel in a month is off peak but an occasional peak trip to the doctor or to the airport is needed sometimes. Therefore in theory it is more equitable not just providing "Lexus Lanes." However, to do all that you must keep more track of almost every vehicle and whether the public is willing to allow that is the biggest unknown as well as protecting the privacy of that data from wandering eyes of Big Brother, whether it is government, insurance companies, employers, parents or divorce lawyers who file open record requests to know where everyone has gone. Remember, years later a President might be requested to provide documents that he made a trip to a National Guard unit or not. In another State a divorce lawyer got the EZ tag records to "prove" spouse was not at work but was seeing another woman. In California at one TMC they have a full time person just to provide "passes" to employers that traffic was too bad to get to work on time.” **[Gaynor]**

“Best: It relates to an important issue.
Concerns: Show me the benefits” **[Bahler]**

"It doesn't appear that there is any basis or need for a monthly budget. Depending on the facilities and extend to which this is applied across all roadways in a region, the true user cost for each trip should be the basis of charging a fee to make that trip. The difference being a higher cost for making a trip in a specific location, at a particular time, and the unique facility. The policy needs to be technology independent. It needs to indicate geographically where this policy applies and what roadways. Why does this policy need to be revenue neutral? If so, why go ahead and have the cost of this system? Doesn't appear you would need it if you are not going to generate any revenue." **[Obenberger]**

"As a program for travel demand management, it is an interesting concept. Is it not similar to what is being tried in Seattle? The policy statement above, gives a foundation for the operational concept, but further definition of the operational concept is necessary to determine if any fatal flaws exist.

From a practical/implementation standpoint, there are a number of unknowns, questions and potential issues. We usually break this down into the following areas: institutional/organizational, business/financial, operational and technical. Usually the most difficult issues to overcome are not technical, though technology can be a critical factor.
How will the "unbanked" population be dealt with?
How will infrequent users be treated?
Need further definition of the business model for the concept. It has been stated that the concept is intended to be "revenue neutral" we take to be with respect to the overall customer base and the total toll costs. What is the expected revenue stream from tolls and supplementary outside funding sources? How much capital, operations administrative and other overhead costs will come out of the revenue stream?

With the heavy vehicle road charging programs, all of a certain class of commercial vehicles is required by law to participate and therefore have an OBU regardless of where they travel. Our understanding is that one cannot simply "opt out" of the program if one wishes to not use congested roads. A significant investment in terms of OBU capital and installation costs is required by either the government (or private contractor/concessionaire) or the customer. This concept would seem to be more palatable for commercial vehicles, but maybe not as much for private vehicles. The benefit of this type of program is that travel data can be kept privately on the vehicle and only summary road use data would then be provided to a central database (i.e. "Big Brother").

In Melbourne, Australia infrequent users may use a "day pass" to pay for travel without having a transponder. They simply call in and give their license plate number and a credit card number. When they use the road without a transponder and are photographed as a potential violator, the "day pass" file is checked before the enforcement process continues. If the customer is found to be a registered "day pass" holder, the violation process stops and images are deleted. This process does not immediately lend itself to the concept of monthly travel allowances." **[Erwin]**

14) Do you have any specific questions or suggestions for application of a CBCP policy?

"Keep me in the loop as you move forward." **[Eden]**
"No" **[Freitas]**
"Of more concern to me is the safety impacts of congestion (crashes, injuries) both primary and secondary. Keeping traffic flowing smoothly is more important to me than reducing congestion. Traffic moving smoothly at 20 mph is better than stop and go traffic. It would be more cost effective to install ramp metering and speed advisories than to do congestion tolls." **[Bahler]**
"See above response." **[Obenberger]**
"See above" **[Erwin]**

15) If we have further questions, may we please contact you in the future?

"Yes" **[Eden]**
"Yes" **[Freitas]**
"Yes" **[Erwin]**

General Comments:

"My personal approach to ITS is that benefits must be understood and concepts of operations and user requirements must be clear before discussing technology (hardware and software). The benefits and concept of operations for the CBCP policy is not clear to me. For example, many, if not most, licensed drivers rarely if ever use congested roadways (high school students, telecommuters, stay/work-at-home parents, transit dependent, and others). The CBCP would appear to pay these drivers to do what they are already doing but would result in no beneficial impact on congestion. Many households have multiple drivers and multiple cars. The person from that household who frequently uses the congested segments could use the transponders/tags for the drivers/cars that are not regularly commuting and thus avoid any out of pocket expense and again fail to impact congestion or generate revenue. That means the burden of CBCP would fall to commercial traffic, to the one-car, one-per person household, and to the one-car household. Increasing fees to commercial traffic results in higher prices for everyone and they cannot easily divert and are often restricted from using some non-freeway routes. The one-car, one-person households is a relatively small group but may be easily diverted to save money. The one-car household may also be a small group but with a large percentage of lower income families or individuals who may have multiple jobs and limited travel options. In addition, there is a lot of scholarly thinking that suggests that for every driver diverted from a congested roadway, another is standing by to take his/her place. So as you can see, there are a lot of questions in my mind about the potential to achieve meaningful benefits from the CBCP policy as described. The high cost for implementation and on-going operations and enforcement. There may also be environmental justice issues." **[Bahler]**

Appendix B8: Responses of Policy Makers and Administrators

1) What administrative issues do you foresee if a CBCP strategy were implemented on your city's/region's highways? What amount of record keeping do you foresee for such a policy? Would there be any specific records that should not be kept on file in order to maintain additional privacy? (e.g. credit card numbers, social security numbers, name, vehicle type, license plate) Would you recommend third-party account distributors to reduce privacy concerns?

"From an administrative standpoint, it can be done because NTTA is currently doing it in the DFW area. I cannot speak to what problems they have run into since I am not familiar with their record-keeping system. However, there is a major difference in what they do and the CBCP proposal. That is, NTTA requires their users to pay or else the user is in violation of the law and can be fined. For NTTA it's easy – if you want to use their facility with a Toll Tag you are required to give them your information and credit card number. People that are uncomfortable with that prospect have the option of simply using a non-Toll Tag lane. In the case of CBCP, you ideally would want every vehicle to have a Toll Tag-type device. Not everyone has a credit card and some people will not be willing to give up personal information. The CBCP infrastructure would need to have some way to allow access to people not comfortable with the Toll Tag system." **[Shon Merryman, Senior Transportation Engineer, City of Carrollton]**

"In a population this size, there are thousands of people who move into and out of the area every month, so keeping the database up-to-date would be untenable. Even if this were possible, it would be unrealistic to believe that even a large majority of these 5 million would give a credit card number to the government for what would essentially be a blank check, since there is no way to estimate on a monthly basis how much it would cost." **[Paul Luedtke, Director of Traffic Operations, City of Garland]**

"Individuals would be reluctant to have their credit cards on file to pay for tolls that could be imposed because of someone borrowing their car." **[Clyde Picht, Council Member, Fort Worth]**

"Costs to local governments…

Record keeping would involve toll tag issues…

You just need a driver's license…

Third party for privacy concerns would be recommended" **[Jay Pritchard, Legislative Aide/Communications Director, Fort Worth]**

"This solution would require a strong governmental organization with a large amount of executive authority to implement vast changes despite pockets of local contention; such a situation does not yet exist." **[Vic Suhm, Transportation Consultant, DFW Airport]**

"Such a system could be simply based on registered vehicle information…every registered vehicle would get its own unique toll tag and credits/payments could be maintained through vehicle registration records." **[Becky Haskin, Council Member, Fort Worth]**

2) Would you anticipate any legal impediments to implementing a CBCP strategy? In addition, do you anticipate any problems with enforcing this policy?

"I do not know the specific law regarding this idea. In my personal opinion, the general public will perceive this strategy like a free facility that is being converted to a toll facility. I believe there is also a policy (or possibly even a state law) that prohibits converting existing free roadways to toll roads. I do know there is a state requirement/law that states that once a toll road debt has been paid through user tolls, it must revert to a free road. There are ways to get around this (as NTTA has done), but there are examples of this type of roadway funding – the section of I-30 between Dallas and Ft. Worth was originally constructed and funded this way." **[Merryman]**

"Citizen groups would emerge to sue over having pay twice for using the same road." **[Picht]**

"Many groups would oppose it based on a personal right to mobility" **[Pritchard]**

3) As a policy maker, what would be your primary concerns if a CBCP strategy were to be implemented? What would be the primary concerns of your constituents? (For example, privacy, administrative burdens, and/or technological feasibility.)

"I believe the biggest impediment to implementation will be compliance and enforcement. From a local government standpoint, there will be a concern that this policy will put more of a burden on the local street system. This traffic will not disappear from these major roads; it will simply move somewhere else, most likely to a parallel arterial or other city street." **[Merryman]**

"How do you determine which drivers are in the "region" and therefore would be included in the program?" **[Luedtke]**

"How do you charge those that live outside the area, but transit in or come to work within the toll region?" **[Picht]**

"The landscape of the state right now is a low tax mindset. With the formation of new toll roads in this area from legislation passed in the last session, there had to be assurances that these tolls would not go on existing roads, that the money would go to fund projects specifically in the area that was being tolled, and that there was a viable alternative to the route that would be tolled.

Constituents would be concerned with the financial burden placed on the public." **[Pritchard]**

"Despite its logic, the people would not go for it. At every public meeting, any type of suggestion of user fees has been struck down by policy makers…there is no way that policy makers would go for it in the current climate." **[Richard Ruddell, Executive Director, Fort Worth Transportation Authority]**

4) What do you find most attractive about a CBCP policy?

"The concept of relieving congestion on major highways is attractive" [**Merryman]**

"Revenue generator" [**Pritchard]**

"This policy seems like it would reduce congestion" [**Ruddell]**

"User fees are becoming more acceptable in terms of municipal service, such as garbage collection where residents must "pay-as-you-go"…if such an idea can be shown to ease congestion in theory, then it is worth implementing for regional mobility.

This policy takes the concept of mobile telephones and applies it to roads; one must pay a higher premium rate to talk during peak times, but can overuse resources at night, weekends when resources are abundant when compared to demand for them" **[Haskin]**

5) What do you find least desirable about such a policy?

"The implementation, education, and enforcement of this policy will be somewhere between extremely difficult and impossible." **[Merryman]**

"Toll lanes, I can live with, but user fees on tax built roads, I can't…" **[Picht]**

"In this landscape the issue would never fly. The legislature has put the policies in place with the creation of Regional Mobility Authorities to fund projects on the local level using public and private revenue sources.

No…this strategy although well thought out and somewhat practical in theory, would place too much of a burden on the taxpayer. As I said before, the passing of HB 3588, which created the Regional Mobility Authorities, should address congestion issues." **[Pritchard]**

6) What problems of equity do you see in a CBCP policy? Do you feel everyone would have adequate/reasonable access to the tolled network, regardless of income?

"If it is a free road before this policy is implemented, people will continue to try and treat is as such, regardless of whether or not there is an attempt to deny them access. I do not foresee income as a deterrent or an issue in this regard." **[Merryman]**

"How would we distribute the money equitably? Some residents would be priced off the no-longer freeway." **[Picht]**

"Most of these 5 million are people who never drive on the congested roadways but would still be entitled to receive $50.00 every month when they aren't doing anything to help out the system – roughly $250 million per month

The inequities involved would be unacceptable to the public as well. You would have motorists living in one area where they have no opportunity on a regular basis to add to the congestion receiving money from someone who has few other choices.

Ultimately, it will be the poor who suffer because they will not have access to as many jobs from their home as someone who can afford to commute a greater distance. This is somewhat the case now-congestion pricing would only make it worse." **[Luedtke]**

"Cost of commuters getting to work. DFW area has the highest amount of commuters in Texas. The reason for this is that the cost of living within a certain radius of downtown and other high economic areas is costly. Real estate prices on the outskirts of town are generally less. This, along with the increase in prices of gasoline, would have an adverse effect on the already economically challenged working class citizen." **[Pritchard]**

7) If revenue is generated, do you anticipate any issues regarding splitting the revenue between local, state and federal governments, since different roads are managed by different agencies?

"Without a doubt, yes. In the past, some local and county agencies have helped to fund the construction of state facilities. Often, there is a local match requirement for the state to even consider these projects for construction. When these projects were originally constructed, the cities and counties providing the local match did not foresee even the remotest possibility that the project they were helping to fund could generate revenue in the future. If this changes, they will be looking to get some return on their investment." **[Merryman]**

8) How important is public support for implementation of this policy? Do you feel that people will support CBCP?

"The public does not see value in the roads that they drive on; one must prove that there is value before they will stop wasting road space." **[Haskin]**

"This is the number one obstacle you will face and you cannot succeed without it. I don't believe it will succeed because the minute this concept is announced there will be a major public outcry against it. Political forces will try to kill it before it has a chance to gather any momentum." **[Merryman]**

"I don't think the public is ready (and I'm not sure they ever will be) for dynamic congestion pricing – especially when plain vanilla congestion pricing hasn't been tried in the region yet. People choose jobs and where they live based on an expected commute cost. If you start changing that dynamically from hour to hour or even month to month, it is going to be more than people can accept because you can't change your commute that fast – it essentially requires one to either move where you live or where you work." **[Luedtke]**

"Public support is vital and people would not support it in today's climate." **[Pritchard]**

"There is a huge public hurdle to taxing existing lanes which already been paid for.

Public would say 'no way'." **[Ruddell]**

"Public would not go for this policy right now, as congestion has not reached levels where people would be willing to pay for time in terms of efficient drive-times. Texas does not yet have the densities to support any type of alternative transportation strategies." **[Suhm]**

9) Under a CBCP policy for the Dallas-Ft. Worth region, where should the geographic cut-off be for regular users of the DFW freeway system? Who would be classified as residents (with the right to acquire a transponder) and who would be classified as guests (having to prepay into the system with each trip on a freeway during congested times)?

"It probably depends upon which freeway is chosen, but theoretically, it would need to include everyone in Dallas and Tarrant counties. There are many people that commute from outside of these counties, so it would also need to include much of Collin and Denton counties." **[Merryman]**

"If the net were cast wide enough to include all drivers, then the area would be at least 120 miles from the centers of downtown Dallas and Fort Worth. Assuming that is the case, the number of drivers would be approximately 5 million people…If the net were not cast this large you would miss many of these who drive the furthest.

In a population this size, there are thousands of people who move into and out of the area every month so keeping the database up to date would be untenable." **[Luedtke]**

10) Assuming that congestion-pricing revenues (in excess of administration costs) are to be allocated among residents with drivers licenses in the region, how should the revenue be allocated? Should it be allocated uniformly? Or based on age, number of dependents, work status (e.g. student, retired, and full-time versus part-time employees) and/or other factors? If yes, then how?

"Ideally, revenues would not be re-distributed to people who exceed the $50.00 limit. However, you will not be able to track these people if they pay with cash every time they use the system. Administratively, it would be difficult to issue rebates to everyone with a Driver's License on a monthly basis. Are you going to write a check to each of these people every month? I would imagine the administrative costs associated with this are astronomical." **[Merryman]**

11) What *exceptions* should be made for a CBCP policy? Are there any users of the system who should partially or fully exempted from congestion pricing charges? If so, who are these users and/or what vehicles do they drive? (For example, buses, postal service vehicles, police cars, emergency vehicles, and other public services, taxi cabs, persons with disabilities, welfare-to-work participants.)

"I would only make 2 exceptions: emergency vehicles and mass transit/very high occupancy vehicles, such as buses, airport shuttles, etc. Everyone else should be treated equally." **[Merryman]**

12) If you are familiar with freeway corridors in Austin and/or the Dallas-Ft. Worth region, please circle which of the following freeways you feel would be the best candidates for such a policy and please note why.

Austin: I-35, Loop 1 (Mopac), Highway 71 (Ben-White), US-13, SH-130, US-290

Dallas: Northwest Irving/DFW corridor, IH-30, IH-820, LP-288, US-67, IH-20, US-287, IH-635, LP-12, SH-183, US-187

"I am not sure that there is a "best" candidate, but of these roads, I would say SH 183 has the most potential because it does not carry as much traffic from outside of the DFW area as some of the other highways listed. I would not use portions of Loop 12 in Dallas - it functions more like an arterial road instead of a highway." **[Merryman]**

"Governor Perry's Trans Texas Corridor plan. Also: I35W, IH820 SH183" **[Pritchard]**

13) Would you advocate any congestion management policy *other than* CBCP for implementation in your city/region? If so, why?

"I believe TxDOT has the right idea in that the additional capacity they are providing on major highways is High-Occupancy Toll. By doing this they can recoup at least some of the cost for major construction projects. This is a form of congestion pricing, but it does not impact the existing free lanes." **[Merryman]**

"Perhaps getting rid of the gas tax, which is a regressive tax, and implementing a CBCP strategy modified to raise income for local road districts." **[Suhm]**

"How about requiring that all four lane (or greater) highways within the target area include a rail track that could be used when traffic reached a level that would support a train?" **[Picht]**

"Governor Perry's Trans Texas Corridor plan takes an approach of advocating true public/private partnerships." **[Pritchard]**

14) Do you have any specific questions or suggestions about CBCP?

"I would question how financially feasible this policy is. I don't know how many vehicles there are in the DFW area alone that would qualify, but assume there are 1 million out of a population of about 5 million people. Doing some quick calculations that would mean if every one of these vehicles gets a toll-tag type device with $50.00 in it every month, you would need to come up with $50 million dollars each month just to fund it." **[Merryman]**

"It will take thinking like this in order to solve congestion problems now into the future.

I believe the CBCP as described needs to be fleshed out to a much greater degree ..." **[Luedtke]**

"The toll road funding concept is perhaps practical, but often there are no funds to set aside to reconstruct a toll road into a freeway upon payment of the road. For example, I-30, which caused many accidents due to different design of offramps and too few ramps." **[Haskin]**

15) Are you willing to be contacted in the future for more detailed discussions of the strategy?

"Yes." **[Merryman]**

Appendix B9: Responses of Commercial Users

1) As a commercial user of the freeway system, what would be your primary concerns if a CBCP strategy were to be implemented? (For example, privacy, administrative burdens, and/or technological feasibility.)

"Wouldn't really be a problem" [**Babette Griffin, Ebby Halliday Real Estate, Dallas**]

"This policy would most likely hurt our delivery drivers; delivery drivers are able to plan ahead for ways to make delivery on time. Adding a cost to driving would only lower their salaries." **[Valerie, Catering Manager]**

"The biggest concern would be where the brunt of the administration costs would be.

How negatively would this policy reflect on our city, and how would that affect our attractiveness in terms of economic development?" **[Sandra Hentges, Vice President of Public Policy, Greater Austin Chamber of Commerce]**

2) What limitations do you see with such a policy?

"Since we must standardize our working hours to the nationwide working hours, our current policy would not allow us to adapt to the new policy." **[Ingrid, Branch Vice President, Compass Bank]**

"We pay our delivery drivers on an hourly basis and we do not compensate them for gas, and probably not for tolls. Any additional costs to drive would be paid for by the driver." **[Valerie]**

"In Austin, there are no alternatives to driving.

Such a policy only would work if the entire city is congested." **[David Smith, Independent Contractor]**

"The policy seems very bureaucratic…"big brother"…how would you sell it to the public" **[Jackson, Vice President, PBS&J]**

3) What do you find most attractive about a CBCP policy?

"Our services have to be offered at off-peak hours because of the high traffic problems. If we could get to a neighborhood in a few minutes during a normal working day, we'd pay $10.00." **[Thomas Rhomadka, General Manager, Trash King, Dallas]**

"Traffic mobility is related heavily to environmental concerns; businesses would be supportive of anything to keep Austin from reach(ing) non-attainment pollution levels.

This policy allows for the government to capture the trucking industry. Truckers actually are very reliant on timely deliveries and a large burden of the system could be levied on them." **[Hentges]**

"This policy would be great if you were to see significant change for a significant time." **[Blatnik]**

4) How dependent is your organization's profits on travel times/costs?

"Very dependent" [**Rhomadka]**

"Nearly all of our transportation is outsourced to a courier service, so that policy would have very little impact on us." **[Occidental Chemical]**

"We're very dependent on when we need to have our food delivered. However, it sounds like your policy would not be in effect during lunch, which is the time when we do the most business. Our breakfast volumes are much smaller than lunch." **[Valerie]**

"I'd be willing to pay a premium to guarantee that supplies would be at the job-site on time." **[Smith]**

5) What changes in employment would you make under a CBCP policy? Would you pay for your employees' congestion tolls incurred on their way to/from work? Would you be willing to change your work schedule? (Please note that the congestion toll paid might be compensated by the travel time savings and increased reliability).

"We might stagger teller's hours based on when the most customers came in, assuming that the congestion pricing would change the pattern.

Our headquarters would probably not pay any additional benefits for tolls." **[Ingrid]**

"The clients that we advise frequently offer flexible, alternative work hours for their employees to help alleviate traffic and as a courtesy to the employee." **[Integrated Employee Benefits]**

"People plan ahead and know how long it will take them to get to work, even if they have lots of congestion. If you factor in meetings, congestion for offices may be a twice a month ordeal.

Lots of people choose to use the flex-time option that we offer—'come late, stay late'" **[Jackson]**

"Telecommuting might become more of an option as technology allows it to become more practical." **[Blatnica]**

6) If CBCP is implemented in your city, with all the freeways being charged, would you consider relocating your organization? If so, which locations would you prefer? (away/towards priced corridors, closer/further away from the Central Business District)

"We might consider moving closer in, if we could guarantee faster service to our customers." **[Rhomadka]**

7) If revenue were to be generated, what would be the best uses of the revenue? Please rank the below listed alternatives. (1 being the highest)

"Addressing air quality would be first, transit alternatives would be second." **[Hentges]**

8) Under a CBCP policy for the Dallas-Ft. Worth region, where should the geographic cut-off be for regular users of the DFW freeway system? Who would be classified as residents (with the right to acquire a transponder) and who would be classified as guests (having to prepay into the system with each trip on a freeway during congested times)?

"Areas closer in town should be priced less on a per-mile basis, so that the authority can hold some small controls on how fast and where development and sprawl take place." **[Hentges]**

9) Assuming that congestion-pricing revenues (in excess of administration costs) are to be allocated among residents with drivers licenses in the region, how should the revenue be allocated? Should it be allocated uniformly? Or based on age, number of dependents, work status (e.g. student, retired, and full-time versus part-time employees) and/or other factors? If yes, then how?

"All residents should receive equal credit…not everybody lives near the Central Business District." **[Hentges]**

"You might want to aggregate people into broad, general categories…such as office workers, home-based businesses, etc." **[Jackson]**

10) If you are familiar with freeway corridors in Austin and/or the Dallas-Ft. Worth region, please circle which of the following freeways you feel would be the best candidates for such a policy and please note why.

Austin: I-35, Loop 1 (Mopac), Highway 71 (Ben-White), US-13, SH-130, US-290

Dallas: Northwest Irving/DFW corridor, IH-30, IH-820, LP-288, US-67, IH-20, US-287, IH-635, LP-12, SH-183, US-187

"I-35…also some of the major surface roads might be good around downtown as well." **[Ingrid]**

11) Would you advocate any other congestion management policy other than CBCP for implementation in your city/region? If so, why?

"Increased and more comprehensive [express bus] service that would serve the larger suburbs so that they could ride the bus to work more easily." **[Ingrid]**

12) Do you have any specific questions or suggestions about CBCP?

"There needs to be a concise, simpler policy for the public to understand this.
At first more traditional tolling might be just as effective." **[Jackson]**

Appendix B10: Contact Information for Survey Respondents

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Appendix C1: Political Acceptability of Use of CP Revenues

CP applications are politically difficult to implement since CP adds a price to something that previously was perceived as free. However, theory suggests that enough revenue can be generated from CP so as to offset the costs to the users (Small, 1992). Small (1992) found that public acceptance[21] of a CP policy increases substantially if the policy is presented along with explicit proposals for revenue use. He also evaluated revenue allocation over various alternatives so as to offset negative impacts to a variety of user groups. And he considered adding to public support by making the package attractive to some influential interest groups. He suggested that revenues be used in a manner such that almost everyone affected by the policy enjoys some offsetting benefits and such that a majority find the package beneficial overall.

To increase political acceptability of any pricing policy, revenues should be used so that they provide significant benefits to those holding political power. Gómez-Ibáñez (1992) categorized the people affected by CP into eight groups, of which three are "direct winners" and five are felt to be "direct losers". The winners are: (1) individuals with high values of travel time (usually high income individuals); (2) transit and rideshare travelers who enjoy a service improvement following pricing; and (3) other individuals who "benefit" from the CP revenue. And the losers are (1) auto-captive users with low values of travel time (usually low-income individuals); (2) users who shift to alternate routes in order to avoid paying congestion tolls; (3) users of non-priced routes where traffic increases due to pricing of other roads; (4) individuals who forego trips to avoid congestion tolls; and (5) users who shift to transit/rideshare.

Among those currently driving alone on congested roads, those with a high value of travel time benefit, since their travel time savings can more than offset the toll cost. Current carpoolers also may benefit, since they will enjoy travel time reductions while sharing the toll with others in their vehicle (Small, 1992). Current transit users are also expected to benefit, as long as transit service improves, in order to cater to an increased user group. In contrast, current solo drivers with a low value of travel time are unlikely to benefit by paying the toll and thus are likely to change destination, mode, route and/or departure time, depending on how captive they are to a particular choice. They also may cease making the trip altogether.

The relative size and composition of each of these groups can determine the political acceptability of a particular CP revenue use. Recognizing all these groups and all these factors suggests that it may be most appropriate to use CP revenues for a combination of purposes.

In order to assess the political feasibility of a road pricing policy, Small (1992) identified general stakeholder groups and their interests in such a policy. These include:

- <u>The traveling public:</u> The public is likely to be concerned with pricing and very interested in travel time improvements. They also are likely to be interested in reducing a variety of taxes (e.g., gas, property, vehicle registration, and income taxes), and in addressing privacy issues related to application of ETC technologies.

[21] Small's (1992) study is based on survey of Southern California residents, and so his findings might not be highly applicable to any region.

- State and local officials: Officials are likely to be interested in finding ways to finance transportation projects and services. They also will be concerned with finding adequate public support before embarking on such policy.
- Public transit and taxicab operators: Transit providers are likely to seek increased funding. Taxicab operators may worry about demand falling, and will want the ability to pass on congestion charges to their passengers.
- Truckers: Truckers tend to support higher highway design standards, and oppose any restrictions to truck movements.
- Businesses: Businesses want better transport for their freight, their employees, and their customers. Some will benefit greatly from travel time reductions and/or travel time reliability. However, some certainly will express concern regarding access to customers and others, if roadways leading to them are heavily priced. Finally, there may be interest in using CP revenues to offset business taxes, perhaps in an effort to subsidize employee commutes (particularly for low-income employees).
- Environmentalists: Environmentalists are concerned about emissions-related pollution, reduction in green space, dangers to wildlife, and water run off from motorized vehicle use and roadways. They usually are against new highway construction projects and are likely to be very interested in CP as a mechanism to reign in travel demand and internalize certain externalities. In addition, CP technology may be used to tax vehicle use for environmental reasons, regardless of time of day. (And such technology also could tax travel more heavily on days that high ozone concentrations or other dangerous air-quality situations are likely to arise.)

Appendix C2: Current Practices

The main aim of cordon tolling in Norway (in cities of Bergen, Oslo, and Trondheim) is road financing. The Oslo Toll Ring was pursued in order to generate funds to add new roadway facilities and improve public transportation in the city. 80 percent of the revenues were earmarked for construction of new roads while the remaining 20 percent was allocated for transit development (Hau, 1992a). The revenues from Trondheim's Toll Ring are being used to finance infrastructure that supports public transportation, cycling, and walking (Tretvik, 1992).

Legislation stipulates that London cordon toll revenues to be used for "relevant transport purposes" by Greater London Authority (GLA), T*f*L or a London borough council for a period of 10 years (GLA Act 1999). Table C2.1 (Blow *et al*, 2003, pg. 12) gives the money spent for various transportation-related purposes in the years 2002 and 2003. Though this amount is greater than the revenue generated, it gives an idea of the proportion in which funds were allocated. The CP revenue allocation plan for the year 2003-04 is tabulated under Table C2.2 (Blow *et al*, 2003, pg. 13).

Table C2.1: London's expenditures for various transportation purposes in 2002 and 2003

Spending plans	**2001-02 Expenditures (million pounds)**	**2002-03 Expenditures (million pounds)**
Highways and road traffic	447.7	566.2
Bus services	649.6	871.3
Docklands Light Railway	87.3	85.0
Other services	77.9	134.4
Total	1,262.5	1,656.9

Table C2.2: London's cordon toll revenue allocation plan for the year 2003-04

Initiative	**Expenditures (million pounds)**
Bus network improvements	81
Increasing late-night public transport	3
Safety and security improvement schemes (e.g. expansion of CCTV on buses)	4
Total improving public transport	88
Safer routes to schools	6
Road safety plan	36
Total safer streets	42
Total expenditure	130
Net toll revenues	121

The 9 million pound ifference between total expenditures and the net toll revenues are to be covered by government grants. The spending shows a significant investment in improving transit. Enhanced bus services resulting from the addition of 300 new buses increased the public acceptance for the CP in London. (Deloitte 2004).

The revenues from SR91 express lanes in Orange County, CA are expected to be used to set up an extensive safety program, ensuring rapid clearance of disabled vehicles on the express lanes, road maintenance, and for a state highway patrol (Finch 1996). In case of San Diego's I-15, state legislation requires all net revenues to be invested in transit (Supernak, 2004). Thus, revenues have been used to start a new regional bus service, the Island Breeze (SANDAG, 1999). Toll revenues from the San Francisco Oakland Bay Bridge were proposed to be used to improve transit alternatives (Caltrans 1995). In general, HOT lane revenues in the U.S. are used mainly to finance their construction, operations, and maintenance, as well as fund transit services (FHWA 2003).

Appendix C3: User Opinions on Use of Revenue from Roadway Pricing

Berg (2003) studied the opinion of users and local stakeholder for various CP projects. The findings are tabulated in Table C3.1.

Table C3.1: User opinions about use of revenue from roadway pricing

Project	Survey by	Respondents	Majority opinion	Other opinions	Major Concerns
I-15, San Diego, California	SANDAG and Caltrans	Transit riders	Expand express bus service	Extend carpool lanes	
		Carpool users	Carpool lane maintenance and expansion	Adding regular lanes to I-15	
San Francisco Bay Area and San Diego	California Air Resources Board	Citizen focus groups	Improve transit		
Los Angeles and Sacramento	California Air Resources Board	Citizen focus groups			Transit improvements will not be of use except in the central city
Portland, Oregon	Portland Metro and Oregon DOT	General public	Operation, maintenance & improvement of the priced facility	Add capacity, bicycle, pedestrian, and transit improvements	
Denver, Colorado	Colorado DOT	Commuter focus groups	Construct new value express lanes		Revenues should be used to fund long term transportation solutions
QuickRide on I-10, Houston, Texas	Texas DOT	General public	Transit improvements in the corridor	Add capacity to all freeways instead of HOV lanes only	Revenue from the project should be clearly defined

Feasibility of CP in twin cities, Minneapolis-St. Paul, Minnesota	Humphrey Institute, Minnesota DOT	Transportation professionals and elected officials focus groups	Fund transit		Revenues should be spent on transportation projects only and close to the area where they were raised
		Business representatives focus groups	Highway construction and maintenance		
		Community leaders focus groups	Compensate those economically affected by tolls		
		Peak-period users of the facility	Maintenance of tolled corridor	Maintenance of all roads, public transportation, reduce property taxes, provide low income tax credits	
Hong Kong	Social Science Research Center, University of Hong Kong	General public	Construct new roads	Improve public transportation	

Appendix C4: Expert Opinions of CP Revenue Use

An extensive survey of stakeholders and experts related to the CBCP application on Texas highways was undertaken for project 0-4634 and is described in Chapter 2 of this report. Specific respondent comments are provided in Appendix B.

As a part of the survey transport economists were asked to rank a set of alternatives for use of excess revenues. Most economists wanted any additional revenue to be used to maintain existing infrastructure and/or to add capacity. The next highest ranked alternative was development of alternative modes, such as transit. Those who strongly favored transit improvement were not at all interested in reducing gas taxes – and vice versa. Some respondents suggested reducing general taxes with CBCP revenues. There was not much interest in using such revenues to improve air quality. Table C4.1 gives the rankings that the experts assigned to each alternative. Any unranked alternatives are assumed to hold the lowest ranking.

Table C4.1: Expert opinion for use of CP revenues

Economist	Build new roads	Maintain existing facilities	Improve Transit	Reduce gas tax	Address air quality
McKenzie & Buckeye	3	2	1	5	4
Hartgen	1	2	5	5	5
Levinson	3	2	5	1	4
Roth	2	1	5	3	4
Shearin	4	2	1	5	3
Svadlenak	1	3	2	5	4
Wells	2	3	1	5	4
Litman	4	2	1	5	3
Rufolo	3	2	5	1	4
Munnich	1	4	2	5	3
Gillespie	2	1	5	3	4
Verhoef	1	1			

Note: 1 indicates highest preference and 5 the least.

Appendix D1: Joint Destination-Mode Model Estimation

Model Structure

The standard model's random utility U_{ijmn} for trip *n*, produced in zone *i* and attracted to zone *j* by mode *m* is given by the following equation (for HBW and HBNW trips):

$$U_{ijmn} = \beta_{m1} + \beta'_{m2} Q_n + \beta_{zone} \ln(\beta_{attr}{}' Z_j) + \beta_{time} T_{ijmn} + \beta_{cost} C_{ijmn} + T_{ijmn}(\beta'_{t-per,m} D_n) + C_{ijmn}(\beta'_{c-per,m} P_{mn}) + \varepsilon_{ijmn} \quad (1a)$$

A more constrained model (not considering traveler demographics) was estimated for NHB trips. This is because an individual making a NHB trip from a particular zone might not belong to that zone. So, applying a NHB model with demographics at the zonal level is not really reasonable, since one does not have the data about the home zone of traveler making a NHB trip. The utility expression for NHB trips is given by the following equation.

$$U_{ijmn} = \beta_{m1} + \beta_{zone} \ln(\beta_{attr}{}' Z_j) + \beta_{time} T_{ijmn} + \beta_{cost} C_{ijmn} + \varepsilon_{ijmn} = V_{ijmn} + \varepsilon_{ijmn} \quad (1b)$$

However, the model was estimated by constraining the value of travel time (VOTT) because of data issues discussed later in the chapter. Also, using a logarithmic form of the generalized cost yielded a better fit than a linear form. The following utility expressions were used in the final model.

HBW and HBNW trips:

$$U_{ijmn} = \beta_{m1} + \beta'_{m2} Q_n + \beta_{zone} \ln(\beta_{attr}{}' Z_j) + \beta_{imp} \ln(C_{ijmn} + VOTT * T_{ijmn}) + (C_{ijmn} + VOTT * T_{ijmn})(\beta'_{per,m} D_n) + \varepsilon_{ijmn} = V_{ijmn} + \varepsilon_{ijmn} \quad (2a)$$

NHB trips:

$$U_{ijmn} = \beta_{m1} + \beta_{zone} \ln(\beta_{attr}{}' Z_j) + \beta_{imp} \ln(C_{ijmn} + VOTT * T_{ijmn}) + \varepsilon_{ijmn} = V_{ijmn} + \varepsilon_{ijmn} \quad (2b)$$

Where:

U_{ijmn} = Utility for a trip *n* produced in zone *i* attracted to zone *j* by mode *m*

β_{m1} = Mode specific constant for mode *m*

Q_n = Vector of demographics (indicator variables) of individual *n*

β_{m2} = Coefficient on Q_n corresponding to mode *m*

$\ln(\beta_{attr}{}' Z_j)$ = Zonal attraction term for zone *j*

Z_j = Vector of zonal attributes of attraction-end zone *j*

C_{ijmn} = Cost of travel from zone *i* to zone *j* by mode *m*

T_{ijmn} = Total travel time from zone *i* to zone *j* by mode *m*

VOTT = Value of travel time

D_n = Vector of demographics (indicator variables) of individual *n*

$\beta_{per,m}$ = Coefficient on D_n corresponding to mode *m*

ε_{ijmn} = IID gumbel error term

The MNL probability that a trip *n* produced in zone *i* attracted to zone *j* by mode *m* is given by:

$$P_{ijmn} = \frac{\exp(V_{ijmn})}{\sum_{j'}\sum_{m'}\exp(V_{ij'm'n})} \tag{3}$$

The various components of the above formulation are discussed in much more detail later in this chapter. The models specified above are non-linear in parameters and hence cannot be estimated using standard modeling software. The model estimation procedure was coded in GAUSS (produced by Aptech Systems, Inc.) matrix programming language. The GAUSS codes for estimating nested logit (NL) and MNL models for joint destination-mode (DM) choice were developed from basic logit model codes given in Train (2002). The codes allow for estimation of both potential nesting structures (destination at a higher level and mode at a higher level) as well as standard MNL. Sometimes the program cannot handle the entire data set at once (depending on computer capabilities). In such a case, the data has to be manipulated in parts and the log likelihood computed for each part. A sum of all log likelihoods is maximized. The codes require the user to specify a set of starting values for all coefficients. For estimating MNL models the starting values were taken as zeros. For NL models the coefficients obtained from MNL models were used as starting values for the explanatory variables and a value of one for the logsum parameter. GAUSS's MAXLIK routine was used for computing the gradients.

The NL model estimates suggested negative logsum parameters for both HBNW and NHB trips (destination at a higher level than modes) which is inconsistent with utility maximizing behavior. For NL models with modes at a higher lever than destinations, the logsum parameters (inclusive value coefficients) exceeded one for HBNW and NHB trips, suggesting that the formulation is consistent with utility maximizing behavior for only a particular range of the explanatory variables but not all values (Train, 2002). So, MNL models were used for travel demand model application.

The following section discusses the data source and important sample characteristics. The data assembly procedure and the assumptions are also mentioned.

Data Source and Assembly

The data used for this study was the DFW household activity survey, a revealed preference survey conducted by the North Central Texas Council of Governments (NCTCOG) and Applied Management & Planning Group in 1996. NCTCOG provided the data for this analysis. The survey collected demographic characteristics of individuals and households and recorded all the activities performed by the individuals on the day of the survey. Of the 9,398 households sampled for the survey, only 4786 provided information (including partial and complete travel diaries). NCTCOG provided the data as an activity diary, a household data file, a persons data file, and a vehicle data file. Some of the important sample characteristics are given in Table D1.1.

The DFW metropolitan region consists of Collin, Dallas, Denton, Ellis, Johnson, Kauffman, Parker, Rockwall, and Tarrant counties and is divided into 4813 internal traffic survey zones (TSZs) and 61 external TSZs. Figure D1.1 illustrates the internal zones for the DFW region. Figure D1.2 shows the zonal centroids.

Table D1.1: Sample (individual) characteristics of 1996 DFW household survey

	Percentage
Income category	
less than 30,000	18.9%
30,000-49,999	23.4
50,000-74,999	27.2
75,000 and above	30.5
Household size	
1	27.0%
2	35.5
3	15.9
4 or more	21.7
Vehicle availability	
0	18.6%
1	28.7
2	38.5
3 or more	14.3
Race	
Asian/Pacific Islander	2.3%
Black	12.8
White	74.9
Other	10.0
Education	
Below high school	33.4%
High school graduate	35.0
Bachelor's degree	18.1
Master's degree	8.9

The mode shares (percentages) for different trip purposes are given in Table D1.2.

Table D1.2: Mode shares by trip purpose for DFW (%)

	HBW	HBNW	NHB	Overall
Drive alone	88.0%	38.0%	54.6%	54.6%
Shared ride	9.9	55.5	40.8	40.6
Transit	0.9	0.3	0.2	0.4
Walk/bike	1.2	6.1	4.5	4.5

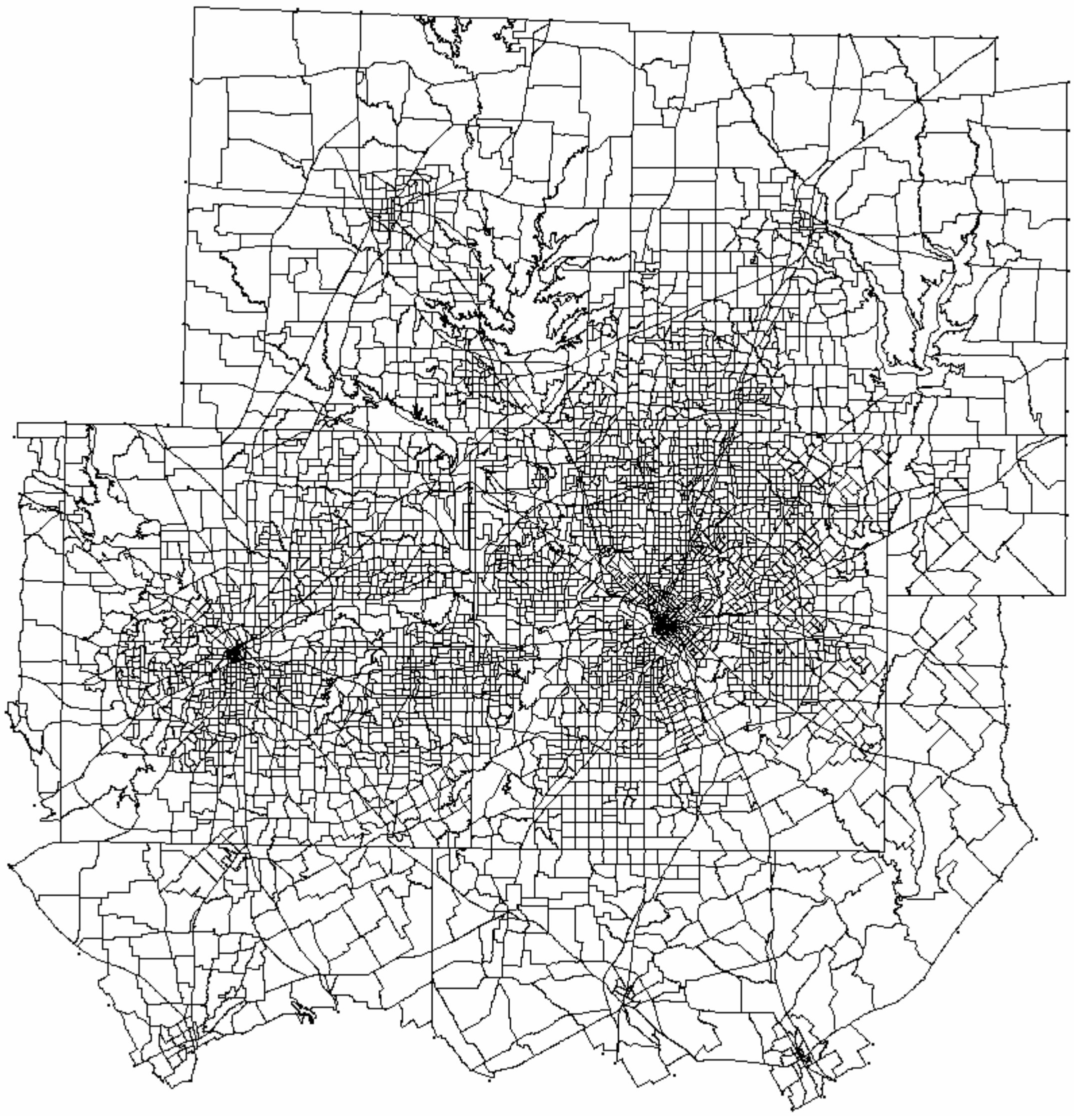

Figure D1.1: DFW's 4813 internal TSZs

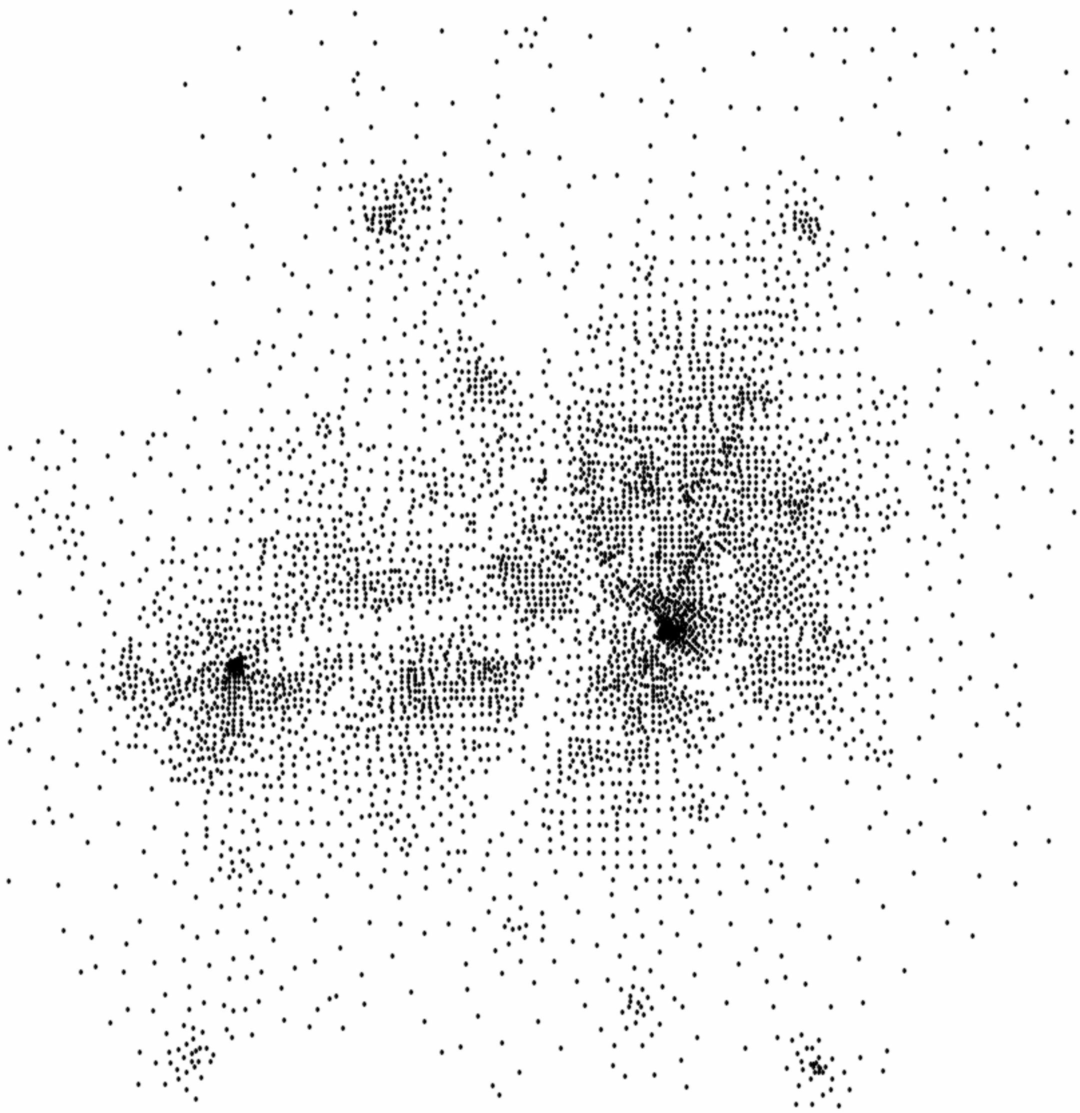

Figure D1.2: DFW's 4874 TSZ centroids

NCTCOG provided the zonal attributes. It also provided LOS data which includes in-vehicle travel time (IVTT), out-of-vehicle travel time (OVTT), and travel cost for peak (6:30 am to 9:00 pm and 3:30 pm to 7:00 pm) and off-peak travel by auto (high occupancy vehicle (HOV) assignment and no-HOV assignment). Transit LOS data included travel times, fare, number of transfers involved and the total transfer time (among other variables) for two cases: walk access and drive access. NCTCOG also provided the Dallas Area Rapid Transit's (DART) on-board survey. Since the number of transit trips in the household survey file was very low, trip records from the on-board survey were also used for modeling (using weights for oversampling bias). The data preparation was carried out in SPSS unless specified.

The steps to arrive at the final data set are given below:

1. TransCAD was used to obtained origin and destination (OD) zones from the latitude and longitude information provided in the travel diary.

2. Trip records which used auto, transit, walk, and bike modes were selected.
3. Walk and bike modes were combined to a single WB mode. Auto trips were labeled as DA or SR based on vehicle occupancy information.
4. Transit on-board survey data was merged with the household survey data. Model variables were selected.
5. Variables indicating trip departure time were created.
6. The dataset was split into three sets based on the trip purpose: HBW, HBNW, and NHB.
7. Trip origins and destinations were recoded into productions and attractions. This involved swapping the origins and destinations if they were the return trips to home for HBW and HBNW trips (in other words ij became ji). No changes were made to the NHB trips; the origin was taken as the production end and destination as the attraction end.
8. Household demographic variables from the household data file were appended to each trip.
9. Indicator variables for income category and vehicle availability were created.
10. Each trip record was repeated nine times and a random zone was assigned as the attraction end to eight of the repeated records so as to have a choice set of nine alternatives (eight random + one chosen).
11. LOS data corresponding to the four modes and departure time was appended. Computation of LOS parameters for this step is discussed later in this section.
12. Attraction-end zonal characteristics were appended using information from the zonal data file.
13. Consistency checks were done, and missing values were imputed from related variables wherever possible. (For example, OD information, income data, vehicle ownership information, and vehicle occupancy).
14. Variables indicating availability of transit and WB modes were created.
15. Weights were assigned based on the actual mode shares to unbias the sample, since DART trips were overrepresented.
16. The SPSS files were converted to ASCII files and then to a format used by the GAUSS programming language.

Since zones were picked with replacement, the code also checks for repetition of randomly selected attraction-ends in the same choice set. Table D1.3 give the five time periods used.

Table D1.3: Time periods used for model application

Time period 0 (T0)	9:00 pm to 6:00 am
Time period 1 (T1)	6:00 am to 9:00 am
Time period 2 (T2)	9:00 am to 3:30 pm
Time period 3 (T3)	3:30 pm to 7:00 pm
Time period 4 (T4)	7:00 pm to 9:00 pm

Peak-period attributes were used for trips in T1 and T3, and off-peak attributes were used for the rest.

Zonal Characteristics

The attraction-end zonal characteristics incorporated in the model include zone land area, population, and total employment (sum of basic, retail, and service employment). All these variables capture the size effect. The rationale for including employment variable is that an individual is likely to choose a zone with more shopping/recreational/dining facilities for his/her non-work trips (e.g. shopping, recreation, eating out). The retail and service employment variables are proxies for availability of such facilities in a zone. Similarly, zones with high basic employment can be expected to attract more work trips compared to other zones. A non-linear specification, as used by Daly (1982), was adopted for the attraction variables. The $\beta_{zone}\ln(\beta_{attr}{}^{/}Z_j)$ term in Equations (2a) and (2b) represents the zonal characteristics. It can also be written as follows:

$$\beta_{zone}\ln(TotalEmployment_j + \beta_{attr,area}LandArea_j + \beta_{attr,pop}Population_j)\ .$$

The coefficients on the attraction terms were constrained to be positive by using exponential functions (Daly, 1982) as follows:

$$\exp(\beta_z)\ \ln(TotalEmplyment_j + \exp(\beta_{attr,a})LandArea_j + \exp(\beta_{attr,p})Population_j)$$

Demographic Characteristics

Some existing research and literature suggest that traveler demographics impact choice of destination. For example, Hason and Pratt (1994) and Madden (1981) suggest that women tend to have shorter commute times/distances, implying that they work closer to home. To capture such effects various demographic variables were interacted with trip generalized cost. The extent to which demographics could be included in the models was restricted by the available zonally aggregate data. Trip productions by two-way classifications of (1) income & household size and (2) income & vehicle ownership were available at the TSZ level. So, the analysis used only income categories and vehicle ownership variables. Aggregate vehicle ownership information was available as the percentage of households by zone by income category that had more than or equal to one vehicle per person in the household. Income information was available as the percentage of households by zone by vehicle ownership category in each of the three income categories. The three income categories are as follows:

Low income: $29,999 or less
Medium income: $30,000 – $74,999
High income: $75,000 and higher

Vehicle ownership indicator variable and generalized cost interaction term as given by $(C_{ijmn} + VOTT * T_{ijmn})(\beta^{/}{}_{per,m}D_n)$ term in Equation (2a) were used in the utility expression. In context of the current model, this term can also be written as $(C_{ijmn} + VOTT * T_{ijmn})(\beta_{per,m}VehicleOwnership_n)$.

This specification allows one to release the constraint that everyone is equally sensitive to generalized trip costs (the sum of monetary cost and the value of travel time).The inherent preferences of individuals in certain vehicle ownership and income groups were captured by using income and VO indicator variables for various modes as given by $\beta^{/}{}_{m2}Q_n$ and $\beta^{/}{}_{per,m}D_n$ terms in Equation 2(a). In context of the current model, this can also be written as $\beta'_{m2} IncomeCategory_n$ and $\beta_{per,m} VehicleOwnership_n$. This specification offers some insight into variations in traveler sensitivities to generalized trip costs, across households with different vehicle ownership and income levels. Values of travel time (which are critical in producing the generalized trip costs) also vary across traveler types, and these parameters are discussed below.

LOS Computations

The transit on-board survey did not have the information regarding the time of day when the trip was made. The trips with missing time of day information were assumed to be made in the peak-period and the corresponding attributes were used. Transit was assumed to be absent for intra-zonal trips. NCTCOG provided the auto travel time skim and distance matrices for peak and off-peak periods. LOS skims corresponding to network without HOV links were used for DA trips and skims corresponding to network with HOV links were used for SR trips. Cost matrices for DA trips were computed by assuming an operating cost of $0.30/mile. This is probably high since most people have access to an insured vehicle and are considering the gasoline and other costs. DA travel costs were divided by the vehicle occupancy to obtain SR travel costs. Average vehicle occupancy of SR trips was used wherever vehicle occupancy information was missing. Average vehicle occupancy (AVO) was used to compute SR costs for trips where people chose DA, transit, or WB. HBW trips had an AVO of 2.35, HBNW trips had 2.9. and NHB trips had an AVO of 2.92.

NCTCOG provided transit LOS for walk access and drive access scenarios. The analysis used walk access data and if not present for some OD pairs the drive access data was used. Total walk time was computed as the sum of access time, wait time, in vehicle travel time (travel time + dwell time), transfer time, and egress time. WB travel times were computed by dividing inter/intra-zonal distances with an average speed of 5 mph and costs were assumed to be zero. WB mode was considered unavailable for trips which took longer than a threshold value of time. This threshold value was obtained from the distribution of travel times for WB trips in the survey data. Instead of choosing the maximum travel time among the WB trips as the threshold value the travel time distribution for WB trips from the survey was used. The travel time beyond which the frequency of trips dropped abruptly was chosen as the critical value. This was arrived upon by judgment and was around the 95 percentile value of the distribution. The critical values of WB times used for various trip purposes are:

- HBW: 23 minutes
- HBNW: 40 minutes
- NHB: 40 minutes

Trips which took longer than these critical values by WB were considered not to have the option of WB. This feature of limited choice set was included in the model estimation procedure.

Estimating the MNL joint DM choice model (as specified by Equations 1a and 1b) resulted in a positive coefficient on travel cost (statistically significant for HBW and NHB trips, and statistically insignificant for HBNW trips) implying a negative VOTT, which is unreasonable. These unexpected results may be due to travelers not perceiving cost rationally. However, travelers can be expected to perceive and be sensitive to congestion tolls. As a result, models had to be estimated by constraining the VOTT. (Mode choice models were estimated in order to obtain a VOTT, but they too indicated a positive coefficient on cost.) Cambridge Systematics, which estimated the mode choice models for NCTCOG, also constrained the coefficients on travel costs for auto and transit since they required the VOTTs obtained from the mode choice models to match the national averages (source: NCTCOG Mode Choice Model documentation, obtained from NCTCOG). VOTT differs across individuals and even by location, to some extent. Researchers have found VOTT (from travel demand models) to range from as low as \$2.00 per hour to about \$20.00 per hour (see, for example, Brownstone et al., 2003). The VOTT for a high income individual can be expected to the higher than that of an individual with lower income. Also, VOTT can be expected to be highest for work trips. Table D1.4 gives the VOTTs assumed in this study.

Table D1.4: Assumed values of travel time

HBW trips	
Low income	\$6.00/hr
Medium income	\$8.00/hr
High income	\$10.00/hr
HBNW trips	
Low income	\$4.00/hr
Medium income	\$5.50/hr
High income	\$7.00/hr
NHB trips	
All income groups	\$5.00/hr

The above VOTTs were used to compute the generalized cost for different alternatives as $C_{ijmn} + VOTT * T_{ijmn}$. Models were estimated with a linear and a logarithmic specification of generalized cost. The latter was chosen since it gave a better fit. Table D1.5 gives the ρ_c^2 values for the two models. Clearly, the logarithmic specification of generalized cost improves the fit for all the models, especially for the NHB trips model.

Table D1.5: Goodness of fit for various model specifications

Trip type	Constants only model	Model with log of impedance		Model with impedance	
	LL	LL	ρ_c^2	LL	ρ_c^2
HBW	-15512.6	-8676.1	0.441	-8828	0.431
HBNW	-35350.4	-15857.3	0.551	-16881.6	0.522
NHB	-16720.2	-8660.2	0.482	-10521	0.371

The ρ_c^2 value, also called a likelihood ratio index (LRI), was computed as:

$$\rho_c^2 = 1 - \frac{LL(\hat{\beta})}{LL(C)}$$

where $LL(\hat{\beta})$ is the loglikelihood at convergence and $LL(C)$ is the loglikelihood at constants. The travel times obtained after traffic assignment were very close to the travel times used for model estimation, as will be seen in Chapter 5. This suggests that the VOTTs assumed in Table D1.4 are not unreasonable.

Weights

Weights were assigned to all the trip records since the mode shares in the initial data set and the processed data set did not match. The mode shares were different since many records (see Table D1.6 for further details) had to be dropped because of item non-response and because transit trip records from the transit on-board survey were added. Sampling weights to account for the relative representation of different demographic groups in the survey and (versus the census, for example) were not used in the modeling stage. The weights assigned to different records for various trip purposes are given in Table D1.6.

Table D1.6: Weights for different records (by mode and trip purpose)

	Number of trips in		Assigned weights
	Initial dataset	final dataset	
HBW			
Drive Alone	5962	5260	1.00000
Shared Ride	699	587	1.05059
Transit	57	4643	0.01083
Walk/bike	86	71	1.06865
HBNW			
Drive Alone	5939	4577	1.00000
Shared Ride	8508	6696	0.97950
Transit	41	3261	0.00969
Walk/bike	894	690	0.99850
NHB			
Drive Alone	4472	3041	1.00000
Shared Ride	3395	2270	1.01702
Transit	9	1483	0.00413
Walk/bike	382	220	1.18074

Appendix D2: Travel Demand Model Application

Procedure

The various steps involved in the TDM application process are discussed below. This process was carried out for the three scenarios mentioned earlier.

1. Productions (by trip purpose) for each zone were split into trip productions corresponding to six demographic groups.
2. The productions by demographic groups (for all trip purposes) were split into five time periods.
3. Joint DM models were used to compute the probabilities of various DM alternatives in attracting a trip produced in an internal zone.
4. The probabilities in the previous step and the productions in step 2 were used to compute the production-attraction (PA) matrices for different time periods, demographic groups, and modes.
5. PA matrices were aggregated across different demographic groups for each time period and trip purpose, for drive alone (DA) and shared ride (SR) trips.
6. Trip return rates and average vehicle occupancy for each trip purpose were used to convert the PA matrices to OD trip tables (vehicle trips) for each time period, trip purpose, and mode (DA and SR).
7. OD trip tables for different trip purposes were aggregated to give OD trip tables for each time period and mode (DA and SR).
8. Trips with an external zone at one or both ends (obtained from NCTCOG's OD trip tables) were added to the OD trip tables obtained in step 7.
9. MSA was used to compute new MSA OD trip tables.
10. The OD trip tables obtained in the previous step were loaded on the network using TransCAD's TA by stochastic user equilibrium module.
11. After convergence was reached, the link flows were used to compute MSA link flows.
12. The network was skimmed for new times and costs, and new DA, SR, and transit times and costs were computed.
13. The times and costs computed in the previous step were used in a feedback for the joint DM choice models in step 3.
14. This process was repeated till the link flow convergence criterion was reached.

The above procedure has been discussed in detail in the following sections.

Productions

NCTCOG provided the zonal productions for each trip purpose. It provided the stratification of the number of trips by income category (3 groups) and vehicle ownership (2 groups) for home-based work (HBW) and home-based non-work (HBNW) trips.
The three income categories are:
Low income: $29,999 or less
Medium income: $30,000 – $74,999
High income: $75,000 and higher

Vehicle ownership (VO) information was available as an indicator variable equal to 0 if the number of vehicles in the household was less than the household size and equal to 1 otherwise. Thus, the joint distribution included six demographic categories.

1. L0: Low income and VO indicator = 0
2. L1: Low income and VO indicator = 1
3. M0: Medium income and VO indicator = 0
4. M1: Medium income and VO indicator = 1
5. H0: High income and VO indicator = 0
6. H1: High income and VO indicator = 1

Since, non-home-based (NHB) trips are not associated with a particular zone, no demographic stratification was available. Zonal productions by trip purpose and demographic group were divided into five time periods using time of day factors. The time of day factors for different trip purposes, obtained from the survey, are given in Table D2.1.

Table D2.1: Time of day factors (splits) for different trip purposes

Time period	HBW	HBNW	NHB
T0: 9:00pm to 6:00am (night off-peak)	0.066	0.183	0.060
T1: 6:00am to 9:00am (AM peak)	0.396	0.291	0.552
T2: 9:00am to 3:30pm (day time off-peak)	0.171	0.312	0.275
T3: 3:30pm to 7:00pm (PM peak)	0.322	0.126	0.072
T4: 7:00pm to 9:00pm (late PM)	0.045	0.088	0.041

Thus, for each zone:

- HBW productions: 6 demographic groups * 5 time periods = 30 sets
- HBNW productions: 6 demographic groups * 5 time periods = 30 sets
- NHB productions: 5 time periods = 5 sets

Total: 65 production sets

These productions obtained from NCTCOG correspond to auto and transit trips only. Since, the analysis involves walk-bike mode also, the number of productions had to be increased to account for the walk-bike productions. The factors by which NCTCOG's productions were multiplied, computed for each trip purpose, are 1.0121 for HBW trips, 1.065 for HBNW trips, and 1.047 for NHB trips. These factors are based on the share of walk-bike mode for each trip purpose, obtained from the household survey. If m is the mode share of walk-bike then the above factors were computed as $\frac{1}{1-m}$. The model application procedure to obtain the OD trip tables is discussed next.

OD Trip Tables

After obtaining the productions for each demographic group by trip purpose and time of day, joint DM choice models were applied. The first step involved computing the utilities for trips attracted to all the zones by different modes, using the zonal attributes and level of service (LOS) parameters for different modes in the five time periods. This was followed by computing the probabilities for each attraction end – mode combination of the trip, as follows:

$$P_{ijmn} = \frac{e^{V_{ijmn}}}{\sum_{j'} \sum_{m'} e^{V_{ij'm'n}}} \tag{1}$$

Where, V_{ijmn} is the systematic utility for a trip made by individual *n* produced in zone *i* attracted to zone *j* by mode *m*.

The above step gives 260 probability matrices of size 4874*4874 corresponding to four modes, six user groups, five time periods, and three trip purposes. The probability matrices were multiplied with the corresponding production vectors to give 260 PA matrices. The L0, L1, M0, M1, H0, and H1 PA matrices corresponding to each time period, trip purpose, and mode combination were aggregated to obtain 60 PA matrices. The PA matrices for DA and SR trips were converted to OD trip tables by using trip return rates. The proportion of trips from home end to non-home end (δ_1) and from non-home end to home end (δ_2) were computed for the five time periods for HBW and HBNW trips. AVO values for SR trips were used to compute person trips to vehicle trips. The AVO was 2.354 for HBW trips, 2.9 for HBNW trips, and 2.922 for NHB trips.

The OD trip table was then computed as:

$$\text{OD} = (\delta_1 * \text{PA} + \delta_2 * \text{PA}^{\text{T}}) \quad \text{for DA trips and} \tag{2}$$

$$\text{OD} = \frac{1}{AVO}(\delta_1 * \text{PA} + \delta_2 * \text{PA}^{\text{T}}) \quad \text{for SR trips} \tag{3}$$

Where PA^{T} is the transpose of PA. The values of δ_1 and δ_2, obtained from the survey, are given in Table D2.2. All NHB trips were assumed to be round trips and trip return rates of 0.5 were assumed.

Table D2.2: Trip return rates for HBW and HBNW trips

	δ_1	δ_2
HBW		
T0	0.577	0.423
T1	0.697	0.303
T2	0.684	0.316
T3	0.118	0.882
T4	0.137	0.863
HBNW		
T0	0.282	0.718
T1	0.734	0.266
T2	0.597	0.403
T3	0.522	0.478
T4	0.495	0.505

The OD trip tables corresponding to different trip types were added to obtain OD trip tables by mode and time of day. NCTCOG provided on OD trip table for different modes. The external trips from NCTCOG's OD trip tables were used in the OD trip tables obtained above.

After obtaining the OD trip tables, the mode-specific constants in the models had to be changed for the predicted shares to match market shares. This process is discussed in the following section.

Changes to the Models

Multinomial logit joint DM models were developed for each trip purpose. By the property of the multinomial logit, the predicted mode share has to equal to the market share (mode share in the survey) when the models are applied to the data on which they were estimated. However, when the models were applied to the entire DFW region the predicted shares did not match the market shares for HBNW and NHB trips. This might be because of the fact that the data used for model estimation was not weighted for demographics. The models capture the effect of income and vehicle occupancy but do not take into account other demographics (for example, gender, education, household size, age, and many others) which might be statistically significant for mode choice. Since the models do not include such demographics, the dataset has to be appropriately weighted before estimating the models. Since, exhaustively assigning weights for all the demographic groups is not practically feasible, the predicted mode shares might differ from market shares when applied to data other than the estimation data.

The alternate specific constants (ASCs), the mode specific constants in this case, represent the effect of demographics not included in the model. So, the ASCs in the models for HBNW and NHB trips were changed and the new predicted mode shares were computed. If these predicted mode shares on region-wide application are different from the market shares then the ASCs were changed again. This was done iteratively till the predicted shares were not very different from the market shares. The predicted shares for NHB trips were close to the market shares after 4 iterations, while the HBNW trips required 6 full iterations. The predicted mode shares for different values of the ASCs and the market shares are given in Table D2.3.

The new models (with changed mode specific constants) were applied to the zonal productions to obtain OD trip tables that reflected market shares. These OD trip tables were then loaded on tot the DFW network. The TA procedure and various issues involved are discussed in the following section.

Table D2.3: Mode shares for different ASC values

	Alternate specific constants			Mode Shares			
	SR	TR	WB	DA	SR	TR	WB
NHB trips							
Market Shares	-	-	-	54.6	40.8	0.20	4.5
Iteration 1	-1.29	-3.53	-2.87	54.3	45.1	0.11	0.44
Iteration 2	-1.4	-3.53	-2.0	56.6	42.2	0.11	1.1
Iteration 3	-1.4	-3.6	-1.0	55.6	41.5	0.09	2.8
Iteration 4	-1.4	-3.3	-0.2	53.7	40.1	0.13	6.1
HBNW trips							
Market Shares	-	-	-	38.0	55.5	0.30	6.1
Iteration 1	-0.889	0.284	-2.218	57.7	41.3	0.76	0.21
Iteration 2	1.50	0.30	-1.20	11.8	87.9	0.16	0.12
Iteration 3	0.333	0.30	-0.888	29.8	69.4	0.40	0.40
Iteration 4	-0.111	0.30	0.112	38.7	59.3	0.52	1.43
Iteration 5	-0.111	0.30	0.225	38.7	59.2	0.52	1.59
Iteration 6	-0.111	0.28	0.888	38.1	56.3	0.50	5.02

Traffic Assignment

The TA methods available in TransCAD include all-or-nothing assignment, stochastic assignment, incremental assignment, capacity-restrained assignment, system optimal assignment, user equilibrium (UE) and stochastic user equilibrium (SUE). UE and SUE are the most commonly used. UE uses an iterative process to arrive upon a convergent solution where the travelers choose the best possible route (in terms of travel time or generalized cost). SUE generalizes user equilibrium by assuming that travelers do not have perfect information of network attributes or exhibit unobserved heterogeneity in preferences. It assumes variable travel cost perceptions for different users. SUE, unlike UE, permits use of less attractive routes such that the less attractive routes have lower utilization than the attractive routes. SUE, hence, is more intuitively reasonable than UE. However, SUE usually requires many more iterations than UE in order to converge. In this case, both SUE and UE assignment methods were tried and SUE was adopted, since it did not require a prohibitively long time. For example, status quo TA for the five time periods took about 1.5 hours when using UE and about 3 hours for SUE. The SUE TA for the MCP cases require about 4 hours each. (It should be noted that the required computing time also depends on one's computer system's capabilities. These models were run on a Pentium4, 3.19 GHz, 2 GB RAM machine.)

TransCAD's Multi-Modal Multi-Class Assignment (MMA) module was used for TA. The joint DM choice model application gave DA and SR OD trip tables for different time periods. The external trip OD trip tables and truck trip OD matrices were taken from NCTCOG. (These include 448,640 truck trips into, out of, and through the region each day.) Two network files were created for each time period – one for DA and truck trips and the second for SR trips. The SR network included the HOV links while the DA and truck network did not have any HOV links. Multi-class assignment was not possible, since all users are assumed to have the same value of travel time while simulating a pricing scenario in TransCAD. Even though values of travel time differs across users (as in Table D1.4), it is not feasible to toll users based on their values of travel time. Thus, a constant $10.00 per vehicle-hour value of travel time was assumed for computing delay-based MCP congestion tolls. (Note that $10.00/hr is the highest among all assumed per-person values of travel time in Table D1.4, but these are per person and average vehicle occupancies range from 2.3 (for work trips) to 2.9 (for recreational trips), so per-vehicle values of travel time are expected to be higher than those shown in Table D1.4.)

TA needs volume delay relationships to route traffic. The relationship between travel time and link volume is given by link performance functions. The standard Bureau of Public Roads (BPR) formulation is used in this study. The BPR function is given by:

$$t = t_f \left[1 + \alpha \left(\frac{v}{c} \right)^{\beta} \right] \qquad (4)$$

Where:

t = Link travel time

t_f = Link free-flow travel time

v = Link volume

c = Link capacity

α, β = Calibration parameters

Default values of 0.15 and 4 were used for α and β respectively. NCTCOG uses separate volume-delay functions instead of the standard BPR, as will be discussed in Chapter 6.

A generalized cost function based on the BPR volume delay equation was used for TA.

$$c_i(v) = k_i + \delta * L_i + \varphi * t_{i,f} \left(1 + \alpha \left(\frac{v_i}{C_i} \right)^{\beta_i} \right) \qquad (5)$$

Where:

$c_i(v)$ = Generalized cost for flow v

k_i = Toll on link i

δ = Vehicle operating cost, assumed as 30 ¢/mile (Edmund, 2004)

L_i = Length of link i

φ = Value of travel time, taken as $10.00/hr

v_i = Flow on link i

The value of link toll (k_i) was taken as zero for the status quo scenario unless the road was a toll road, in which case, the actual toll on the link was used.

Three scenarios – status quo, scenario 1: MCP-on-freeways, and scenario 2: MCP-on-all-roads were simulated in this study. To simulate MCP on a link, drivers have to face the social cost of their trip on that link. So, the difference between the social cost and the personal cost was charged as a toll on the link. Given the BPR, the additional travel time on a link because of the entry of a new vehicle is given by $\frac{dt}{dv}$. From the BPR we have:

$$t = t_f \left[1 + \alpha \left(\frac{v}{c} \right)^{\beta} \right]$$

Differentiating with respect to volume

$$\frac{dt}{dv} = t_f \frac{1}{C} \alpha\beta \left(\frac{v}{C} \right)^{B-1}$$

So, the total delay caused because of the entry of a new vehicle

$$v\frac{dt}{dv} = vt_f \frac{1}{C} \alpha\beta \left(\frac{v}{C} \right)^{B-1}$$, which can also be written as

$$v\frac{dt}{dv} = t_f \alpha\beta \left(\frac{v}{C} \right)^{B}$$

The total delay time multiplied by the value of travel time gives the total cost incurred because of the entry of a new vehicle. This is the value of link toll, in addition to the existing tolls (k_i), to be charged for MCP scenarios.

$$Toll_i = k_i + \varphi * t_{i,f} \alpha\beta \left(\frac{v}{C} \right)^{B} \tag{6}$$

Substituting this in the generalized cost equation gives the expression for generalized cost for a MCP scenario as:

$$c_i(v) = k_i + \varphi * t_{i,f} \alpha\beta \left(\frac{v}{C} \right)^{B} + \delta * L_i + \varphi * t_{i,f} \left(1 + \alpha \left(\frac{v_i}{C_i} \right)^{\beta_i} \right)$$

$$c_i(v) = k_i + \delta * L_i + \varphi * t_{i,f} \left(1 + \alpha(\beta + 1) \left(\frac{v_i}{C_i} \right)^{\beta_i} \right) \tag{7}$$

MCP-on-freeways employed the above generalized cost expression on freeways links and the usual generalized cost expression (Equation 5) for all other links. MCP-on-all-roads employed the above generalized cost expression for all the links.

NCTCOG provided the peak and off-peak hourly capacity for all the links. This information was used to determine the capacities for the five time periods. The peak (T1 and T3) capacities were computed as the number of hours in a time period times the peak hourly capacity. The capacities for the longer off-peak time periods, however, were computed in a differently. The off-peak hourly capacity, given by NCTCOG, represents an average capacity over the 18 hour off-peak period. The hourly link capacities in the daytime off-peak can be expected to be more than average value (provided by NCTCOG) and the nighttime off-peak capacities can be expected to be less than the average value. So, the link capacities for T0 (9 hours at night) were computed as 7.5 times the off-peak hourly capacity, and for T2 (6.5 hours in the day) were computed as 8 times the off-peak hourly capacity. For time period T4 (2 hours following the PM peak) the hourly capacities were assumed to be 0.95 times the peak hourly capacities.

TA Convergence Criteria

TransCAD's convergence criterion was used to define the convergence criterion for TA. It uses the maximum absolute change in all the link flows between consecutive iterations as the convergence criterion. TransCAD recommends a value of 0.01 for the above. TA using this criterion took around 3 iterations for off-peak periods and around 12 iterations for peak-periods.

Boyce et al. (2004) mention a relative gap measure for checking convergence in TA. The above study computes an absolute gap measure as the difference between the total vehicle hours computed with current network volumes and the total vehicle hours computed with all-or-nothing assignment (i.e., flows at the current shortest paths). This absolute gap keeps getting smaller as the solution moves towards equilibrium. Boyce et al (2004) compute the relative gap at the current iteration as the ratio of the absolute gap and the value of the objective function in the current iteration. Since the objective function could be formulated in several ways, the relative gap does not have a universal interpretation. Boyce et al (2004) suggest that a relative gap of 0.01 percent (0.0001) is required to achieve link flow stability and hence assure convergence of TA. The above study also mentions that about 500 iterations of Frank-Wolfe algorithm might be required to achieve a relative gap of 0.01 percent. The study indicates that this process could run into several hours for a single TA, depending on the computational capabilities.

The converged TA gives link flows and travel times as outputs. The network could be skimmed for inter zonal and intra zonal travel times and costs (distances), which are then fed back to the joint DM model application step to establish a feedback mechanism. This is discussed in detail in the following section.

Feedback and MSA

Loading OD information from the revised models on the network, and skimming the network gives LOS data that may differ from the LOS data used to apply the joint DM models. So, the current LOS data could be fed back so that the joint DM models use the current LOS information to compute the OD trip tables. The new OD trip tables could be used for TA and the network could be skimmed again for LOS data. This process might be continued till link flow convergence is reached. This is known as direct feedback. However, as previous research by Boyce et al (1994) has noted, there are disadvantages associated with direct feedback. For example, the direct feedback method may take a large number of iterations to converge or may not even converge (TMIP, 1996).

To overcome these disadvantages, this analysis adopted a variant of the MSA. In this method, the link flows from all the previous iterations were averaged to obtain MSA flows for the current iteration, which form the current iteration's link flows.

The MSA link flow is calculated as:

$$MSAFlow_n = MSAFlow_{n-1} + (Flow_n - MSAFlow_{n-1})/n \qquad (8)$$

where n = current MSA feedback iteration number, $MSAFlow_n$ =MSA flow at iteration *n, and* $Flow_n$= flow resulting from TA in iteration n.

The normal link performance function (BPR in this case) is then used to compute the adjusted travel times and costs, which are fed back into to the trip distribution stage where the joint DM model is applied.

The MSA is applied not only on the link flows, but also on the OD trip tables so as to have a two-way convergence. The OD trip tables from all the previous iterations are averaged to obtain

MSA OD trip tables for the current iteration, which form the current iteration's OD trip tables. The MSA OD trip tables are computed as:

$$MSAOD_n = MSAOD_{n-1} + (OD_n - MSAOD_{n-1})/n \qquad (9)$$

where n = current MSA feedback iteration number, $MSAOD_n$ = MSA OD cell at iteration n, OD_n = OD cell resulting from joint DM model application in iteration n. This MSA feedback procedure is continued till convergence is reached between the flows of the current iteration and the MSA flow in the previous iteration.

Another issue is that, if the LOS values obtained after MSA feedback significantly differ from the LOS data used to estimate the joint DM models, then one could question the validity of the models. So, it was checked whether or not the LOS data after MSA feedback (for status quo) was very different form the LOS data used to estimate the joint DM models. A weighted R^2 measure was computed for the zone-to-zone travel times in different time periods. The OD trip tables used for TA, corresponding to each mode and time of day were used as the weights. Each weighted R^2 measure was computed as:

$$R^2 = 1 - \frac{\sum_i \sum_j w_{ij}(t_{1ij} - t_{MSAij})^2}{\sum_i \sum_j w_{ij}(t_{1ij} - \overline{t_1})^2} \qquad (10)$$

where:

w_{ij} = value in the i^{th} row and j^{th} column of the OD trip table (i.e., number of trips from zone i to zone j)
t_{1ij} = value in the i^{th} row and j^{th} column of NCTCOG travel time matrix (i.e. travel time from zone i to zone j)

t_{MSAij} = value in the i^{th} row and j^{th} column of travel time matrix after MSA feedback

$\overline{t_1}$ = average of all cells in NCTCOG travel time matrix

The weighted R^2 values obtained are given in Table D2.4.

Table D2.4: Weighted R^2 values for comparison of travel times

Mode-time of day	Weighted R^2
DA - T1	0.99424
DA - T2	0.99768
DA - T3	0.99412
SR - T1	0.99536
SR - T2	0.99796
SR - T3	0.99488

The weighted R^2 values above indicate that two travel time matrices are not very different and the joint DM models are probably very valid in using the travel time matrices provided by NCTCOG.

Now that the feedback mechanism has been established, the next question is how many feedback iterations are required. The following is a discussion on various feedback convergence criteria that could be used and the criteria used in this study.

Feedback Convergence Criteria

Various convergence criteria could be used to check for if the feedback model has reached equilibrium. Boyce and Florian (2005) mention several such criteria that could be used in ad-hoc equilibration procedures. Relative gap and gap measures could be computed as a measure of the difference in a particular variable (e.g., flows, travel times) between two consecutive iterations. For example:

Link flow criterion:

$$\text{Relative gap} = \frac{\sum_a \left| flow_{n,a} - flow_{n-1,a} \right|}{\sum_a flow_{n,a}}$$

Travel cost criterion:

$$\text{Relative gap} = \frac{\sum_a \cos t_{n,a} * (flow_{n,a} - flow_{n-1,a})}{\sum_a \cos t_{n,a} * flow_{n,a}}$$

Vehicle miles traveled criterion:

$$\text{Gap} = \sum_a length_a * (flow_{n,a} - flow_{n-1,a})$$

Vehicle hours traveled criterion:

$$\text{Gap} = \sum_a time_a * (flow_{n,a} - flow_{n-1,a})$$

Here, subscript '*a*' corresponds to the link number and subscript '*n*' corresponds to the iteration number. Boyce and Florian (2005) also indicate that all the above measures are satisfactory since all measure the current results' closeness to a consistent solution. Of course, the lower the relative gap (or gap) the closer to equilibrium is the solution. They also indicate that equilibrium solution might not be unique.

This analysis used TransCAD's gap measure to define the convergence criterion. TransCAD's user manual mentions that the convergence test compares flows from the n^{th} assignment iteration with the flows from the $n\text{-}1^{th}$ assignment iteration. If the gap is less than a specified value then the feedback loop is assumed to have converged. TransCAD recommends an ad-hoc value of 0.01. The gap between two data fields is computed as:

$$\text{Gap} = \sqrt{\frac{\sum_{i=1}^{n} (v_i - w_i)^2}{\sum_{i=1}^{n} v_i^{\,2} + \sum_{i=1}^{n} w_i^{\,2}}} \tag{11}$$

where, v_i = i^{th} value in the first data field, w_i = i^{th} value in the second data field, and n = number of records.

After four full iterations of MSA feedback were run for all the scenarios. The above gap measure was checked for the link flows (bidirectional) for all the time periods and scenarios between flows of the 3rd and 4th iteration of the MSA feedback and found to be around 0.01 – 0.015. The results of the 4th iteration were used for analysis. The TDM application procedure adopted in this study makes several assumptions, which are mentioned in the following section. The limitations are also discussed.

Short-term vs. Long-term

The procedure discussed above was used to simulate what we are calling the “short-term” and “long(er)-term” impacts of both the MCP scenarios. In the short run, users are not expected to be able to change their work locations. So, allowing users to choose new destinations for HBW trips under MCP might not be reasonable (at least not in the short run). To enforce this, HBW OD trip tables from the status quo were also used for the MCP scenarios. However, users were allowed to change destinations for HBNW and NHB trips (which may not be possible for all trip types, such as school and doctor’s appointments). In the longer run, users could be expected to change employment locations, so separate HBW trip tables were computed for the MCP scenarios. However, simulating true long term impacts will be much more complicated than this. As seen in Chapter 2, the stakeholders and experts expected employment to become more decentralized and housing to become more centralized under a CBCP policy. If this were to happen, the zonal attributes (for example, employment and population) would change. Thus, the trip production and joint DM models may give different results for the long term. To incorporate all this, one would have to model land use in terms of employment and residential location choices. Such models were not included here due to time constraints. Other limitations of this analysis are mentioned in the following section.

Assumptions and Limitations

The analysis assumes inelastic demand. In other words the number of person trips for MCP scenarios is the same as status quo. The analysis assumes that buses will not have a significant impact on the auto travel times. However, transit travel times could change when network flows change. When the DA and SR LOS are fed back to the joint DM model, the transit times also change in the new MSA feedback iteration. But, since the study does not do transit assignment, new transit LOS data is not available. So, it is assumed that the transit times change in the same ratio as that of SR times. For example, when SR times increased by 5 percent, transit times also were assumed to increase by 5 percent. Transit costs (bus fares) and walk-bike times were assumed to remain constant for all the MSA feedback iterations, which is reasonable.

An important limitation of this procedure is that departure time shifts under MCP scenarios were not considered. Departure time choice models were estimated for different trip purposes but the models were not very intuitive because of the limited explanatory variables that could be used (since information at the zonal level was limited). Hence, time of day factors were used and departure time shifts across time periods considered in the analysis was assumed to be negligible. It was assumed that all the NHB trips are round trips (a trip return rate of 0.5 was used for both directions). This, however, is not true for NHB travel activities during trip chaining. Also, all the possible changes in the long run, were not modeled (especially land use changes). Another limitation is that traffic assignment was done assuming equal value of travel time for all the user groups, since differential road pricing (based on user group) is not feasible. Also, static traffic assignment was used rather than dynamic traffic assignment (DTA) since the application was carried out in TransCAD which does not include DTA. DTA software was not used for this purpose because of time constraints.

Appendix E1: Traffic Impacts

Roadway Network

North Central Texas Council of Governments (NCTCOG) provided the 1999 DFW roadway network used in the analysis. The DFW road network has 26,748 lane miles and is divided into 22,187 links. Figure E1.1 shows the DFW network. The freeways are shown in bold. These include unidirectional and bidirectional links. 9805 centroid connectors have been provided for the 4874 zones. Figure E1.2 shows the network nodes (intersections and link ends). The links are classified into seven categories depending on their free-flow speeds and capacity. In addition to these, extra links that connected zone centroids to the nearest roadway link (i.e., centroid connectors) are added to the network. Table E1.1 gives the number of links and lane miles by each of these facility types.

Table E1.1: Lane miles and number of links by facility

Facility type	# links	lane miles	% lane miles
Freeways	2692	3736.7	14.0
Principal arterials	2389	3909.3	14.6
Minor arterials	4964	8707.5	32.6
Collector streets	6794	7588.5	28.4
Ramps	3056	636.8	2.4
Frontage roads	2229	2135.0	8.0
HOV	63	34.5	0.1
Total	22187	26748.2	-
Centroid connectors	9805	-	-

NCTCOG's assumed free-flow speeds for each link are simply 1.1 times the speed limit on those links or 75 mph whichever is lower (where speed limits are primarily defined by facility type). The freeway links have speeds limits of 60 mph, 65 mph, or 70 mph, and so the corresponding free-flow speeds used were 66 mph, 71.5 mph, and 75 mph respectively. The arterial roads have speed limits up to 60 mph and hence a maximum free-flow speed of 66 mph. The minor arterials have speed limits up to 50 mph. The speed limits for other road types are quite variable. The following section provides a discussion of the joint DM choice model's interpretation and traveler behavior predictions for both MCP scenarios.

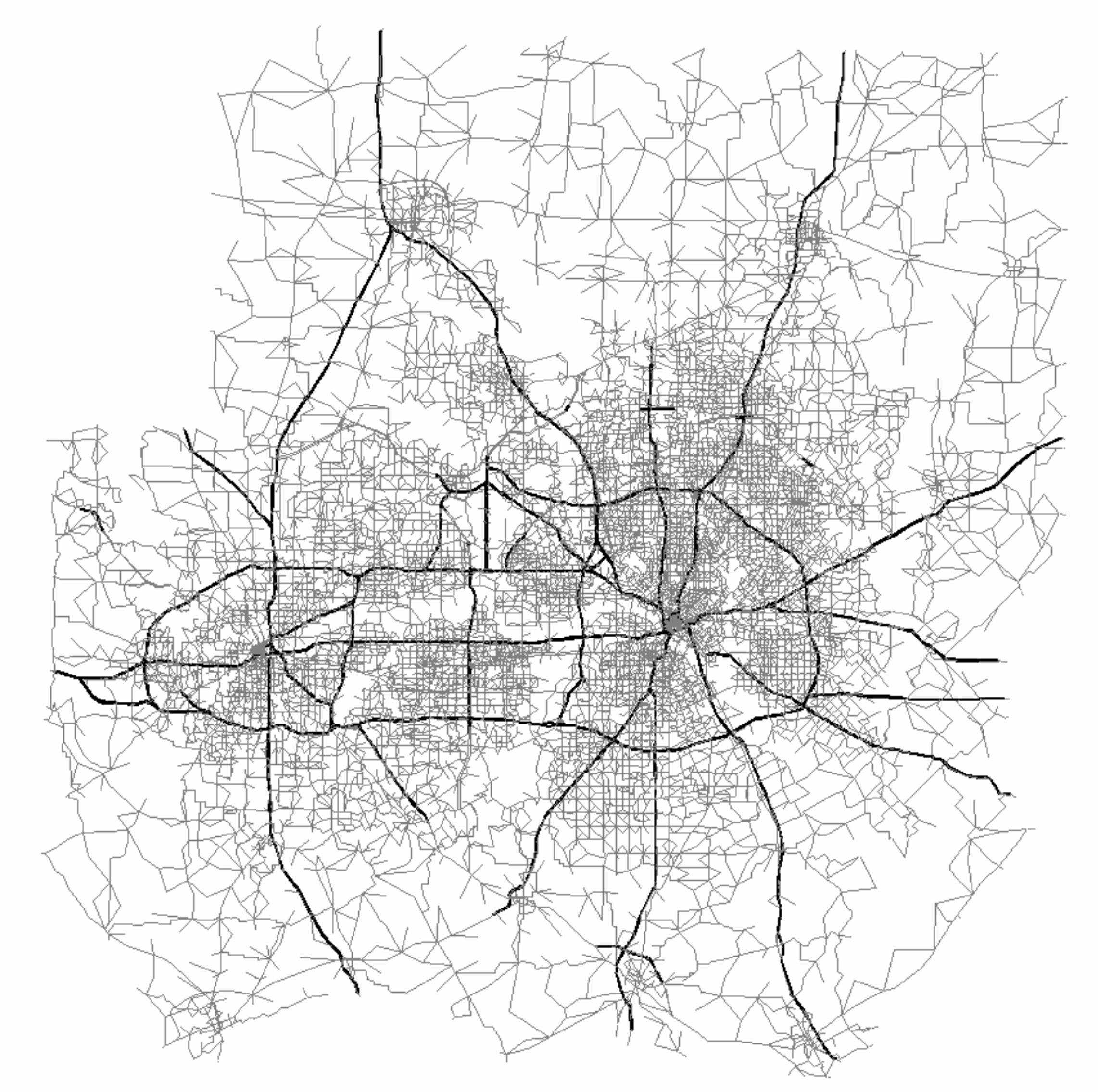

Figure E1.1: DFW roadway network
(31,992 links, bold links indicate freeways)

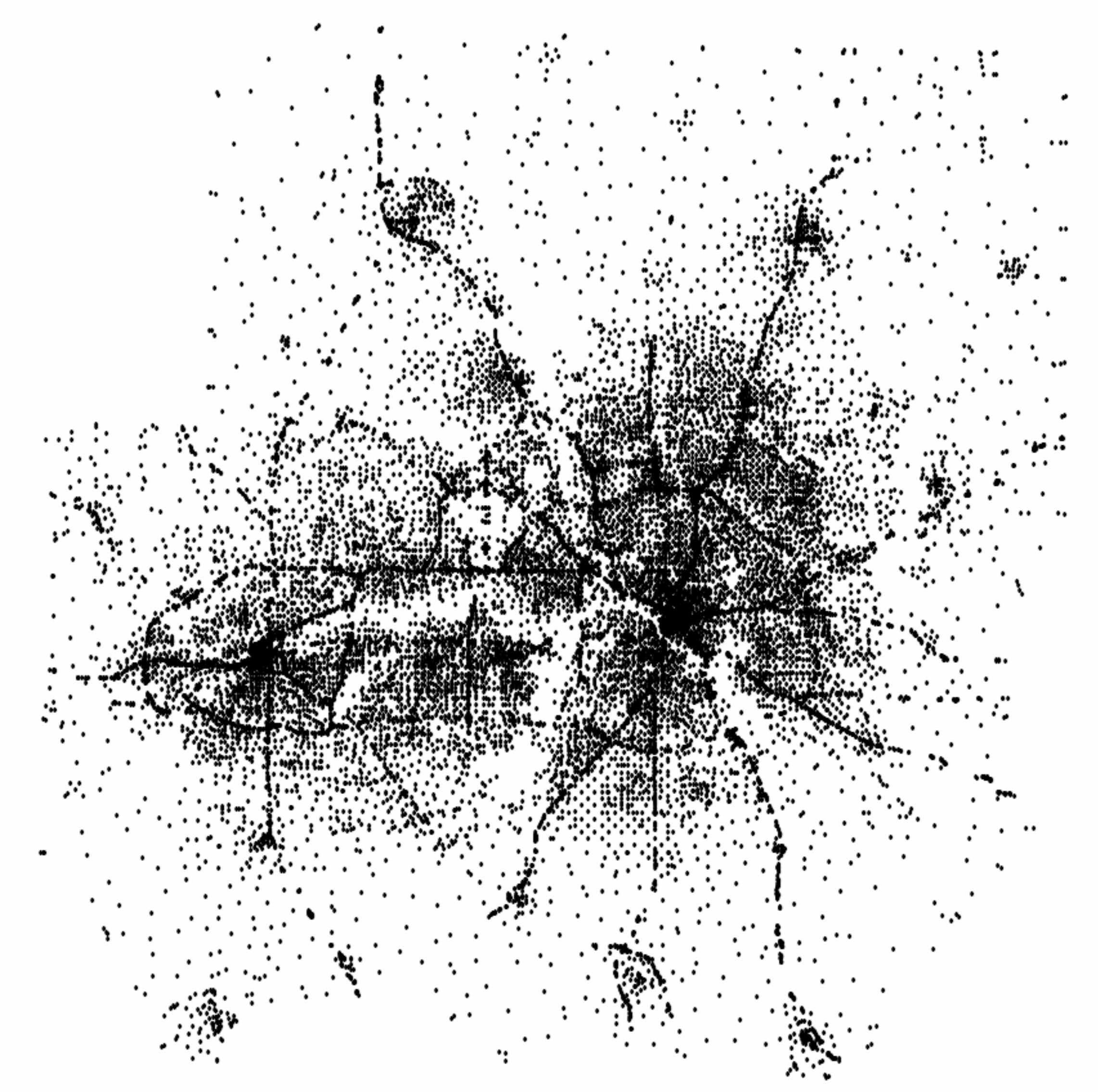

Figure E1.2: DFW roadway nodes
(18,568 nodes)

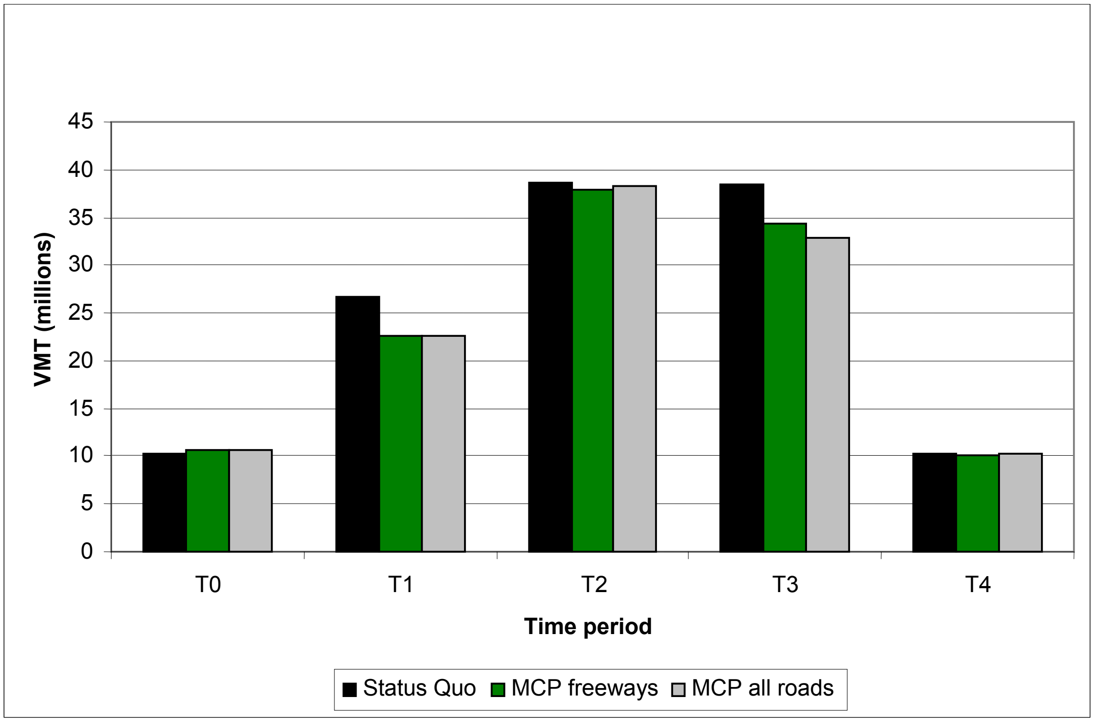

Figure E1.3: VMT by time periods for different scenarios (Short-term)

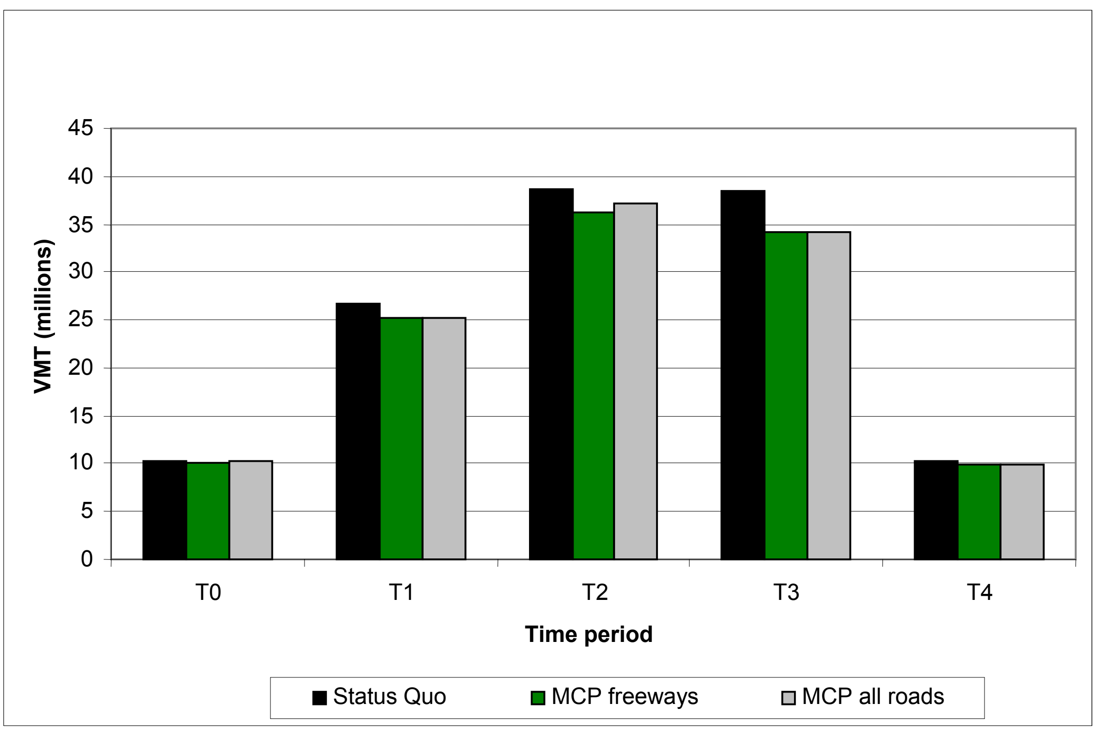

Figure E1.4: VMT by time periods for different scenarios (Long-term)

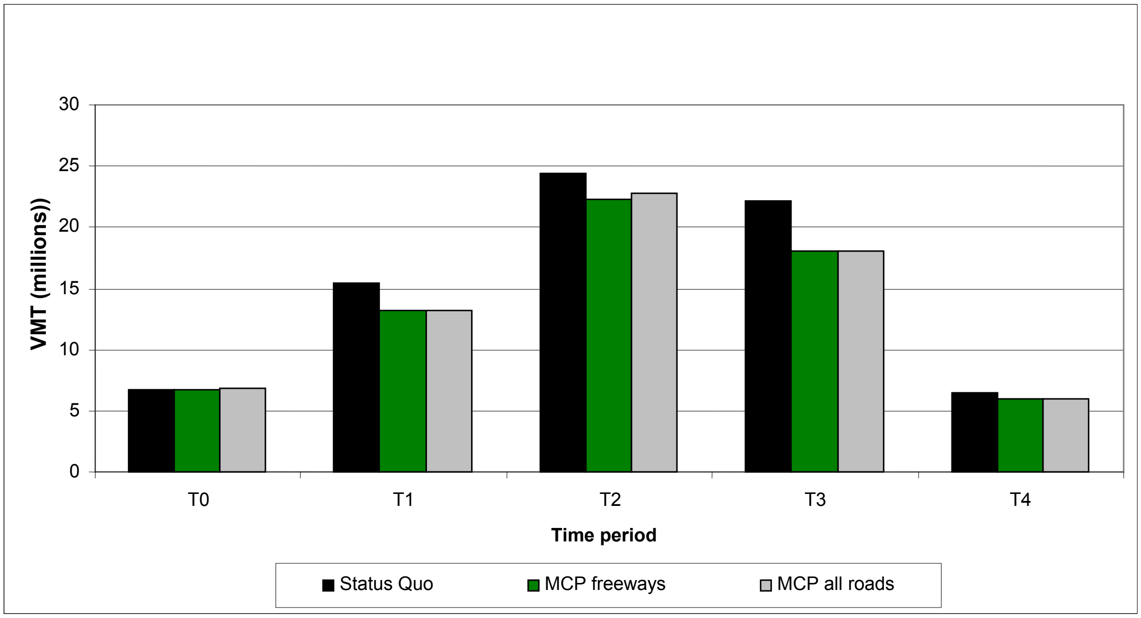

Figure E1.5: Freeway VMT by time periods for different scenarios (Short-term)

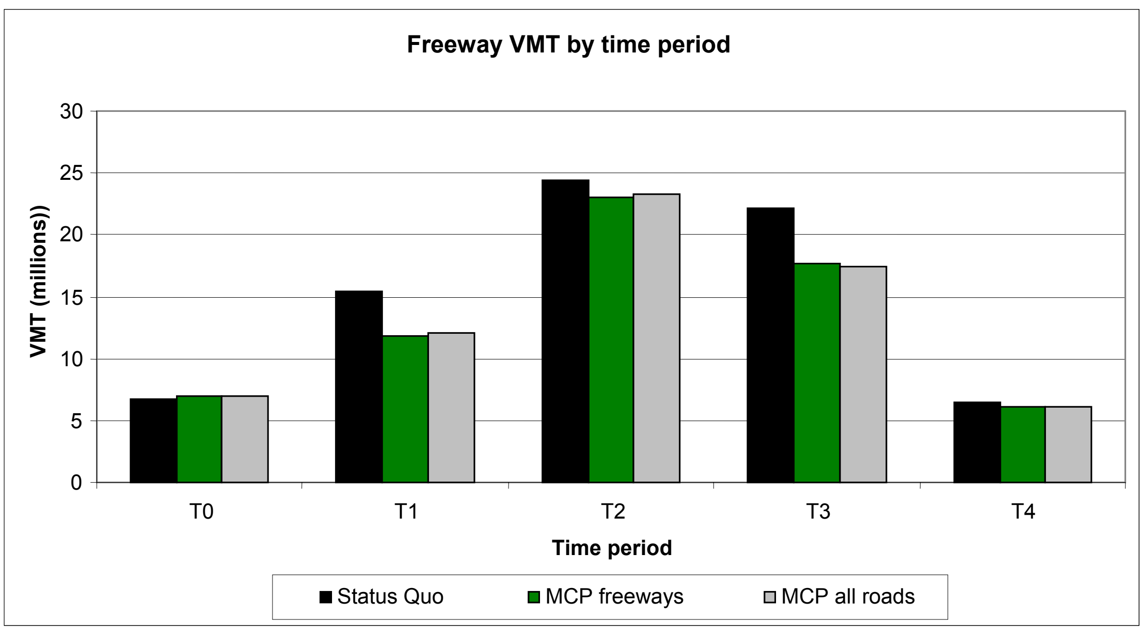

Figure E1.6: Freeway VMT by time periods for different scenarios (Long-term)

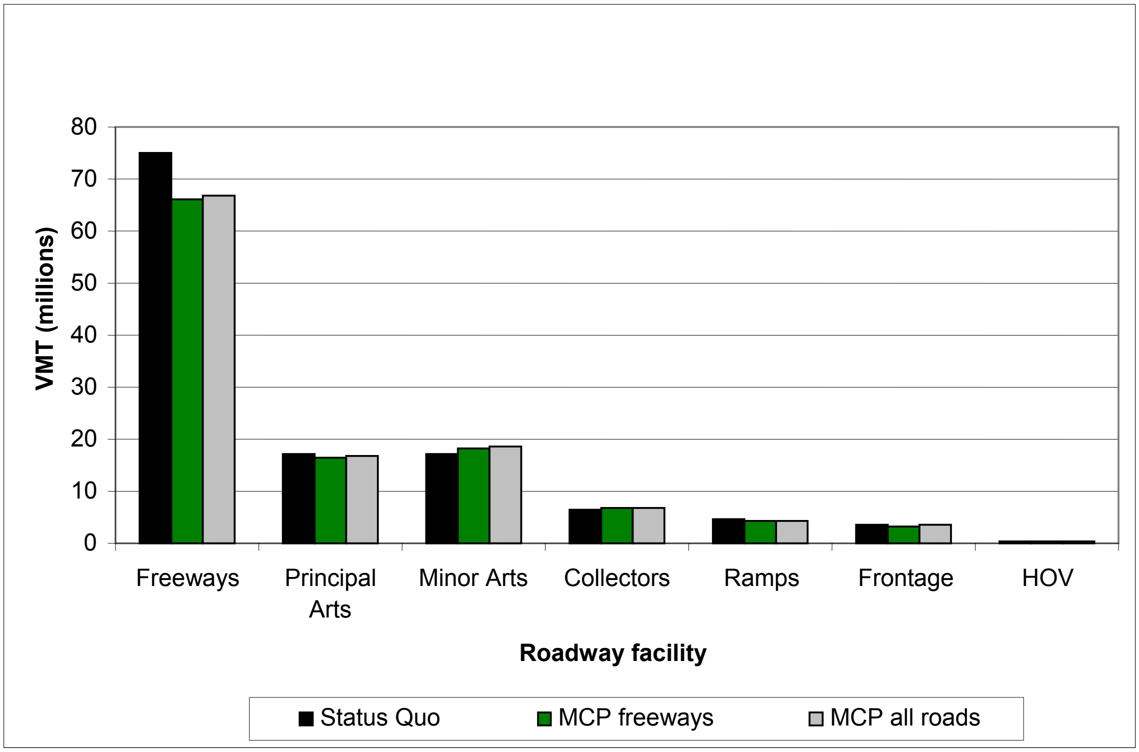

Figure E1.7: Daily VMT by roadway facility type for different scenarios (Short-term)

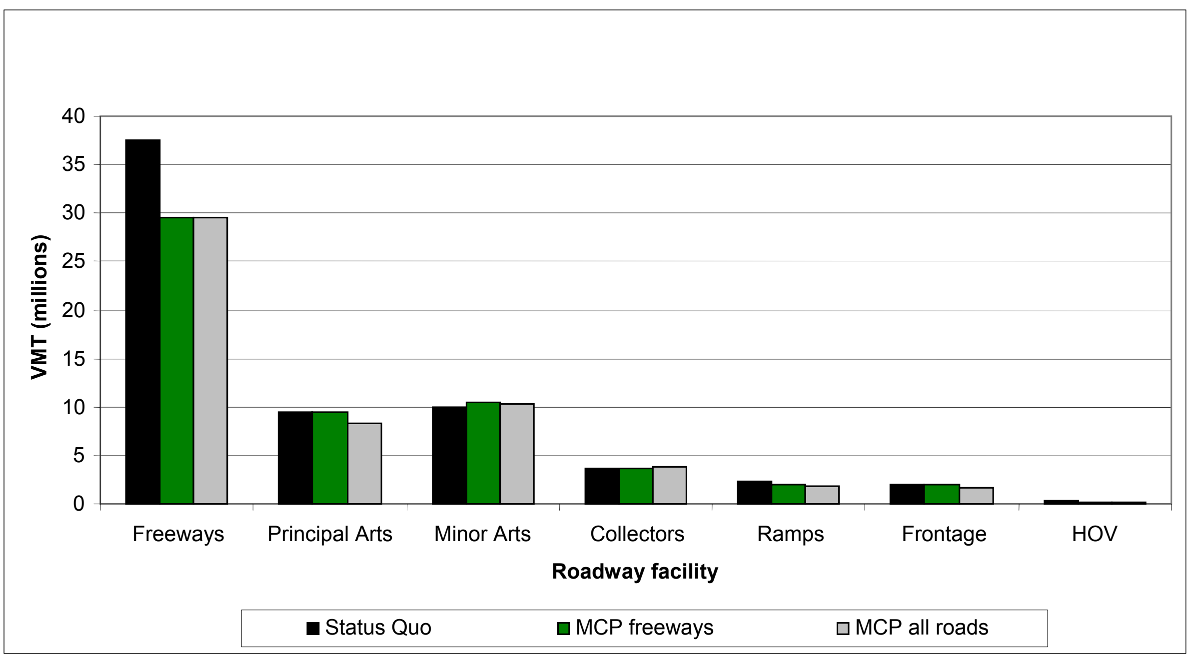

Figure E1.8: Daily VMT by roadway facility type for different scenarios (Long-term)

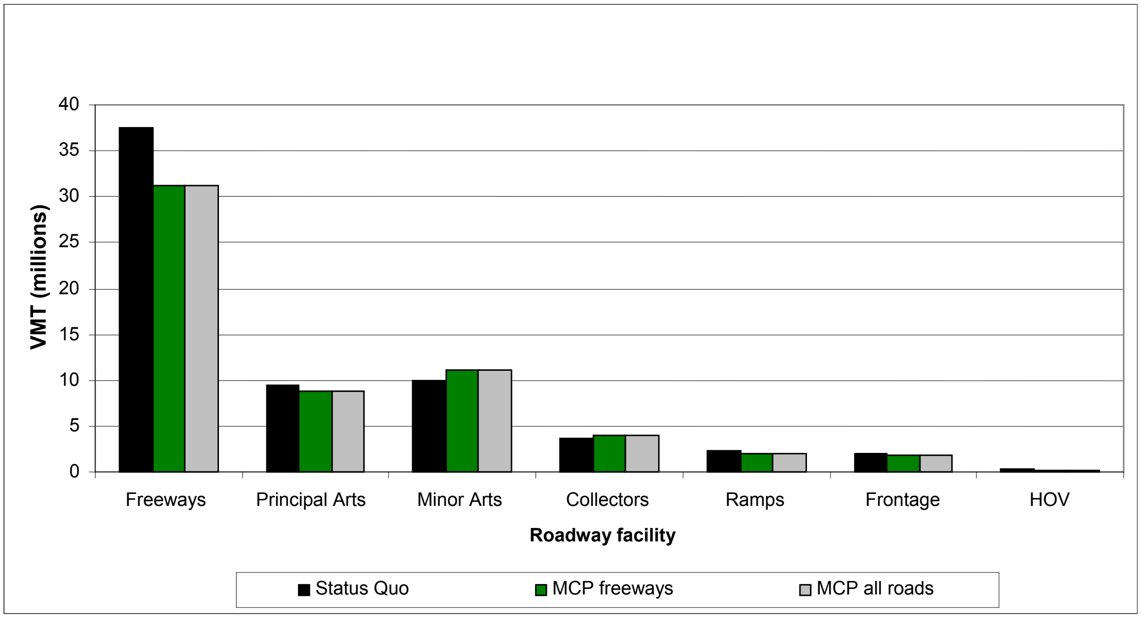

Figure E1.9: Peak-period (AM and PM peaks) VMT by roadway facility type for different scenarios (Short-term)

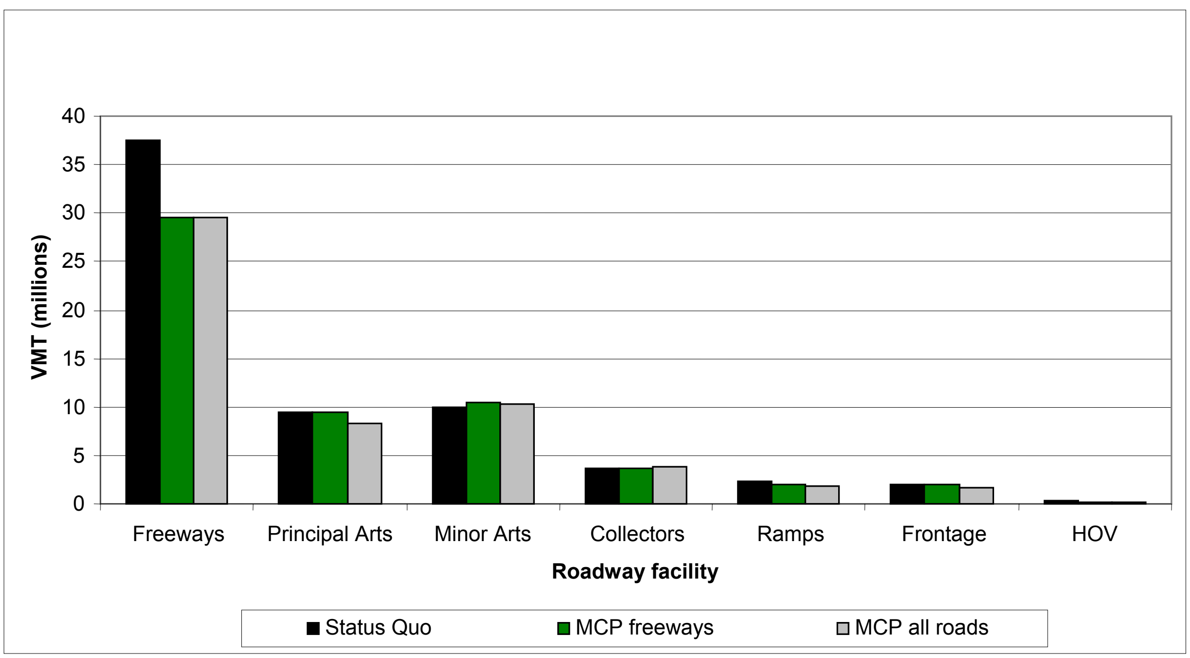

Figure E1.10: Peak-period (AM and PM peaks) VMT by roadway facility type for different scenarios (Long-term)

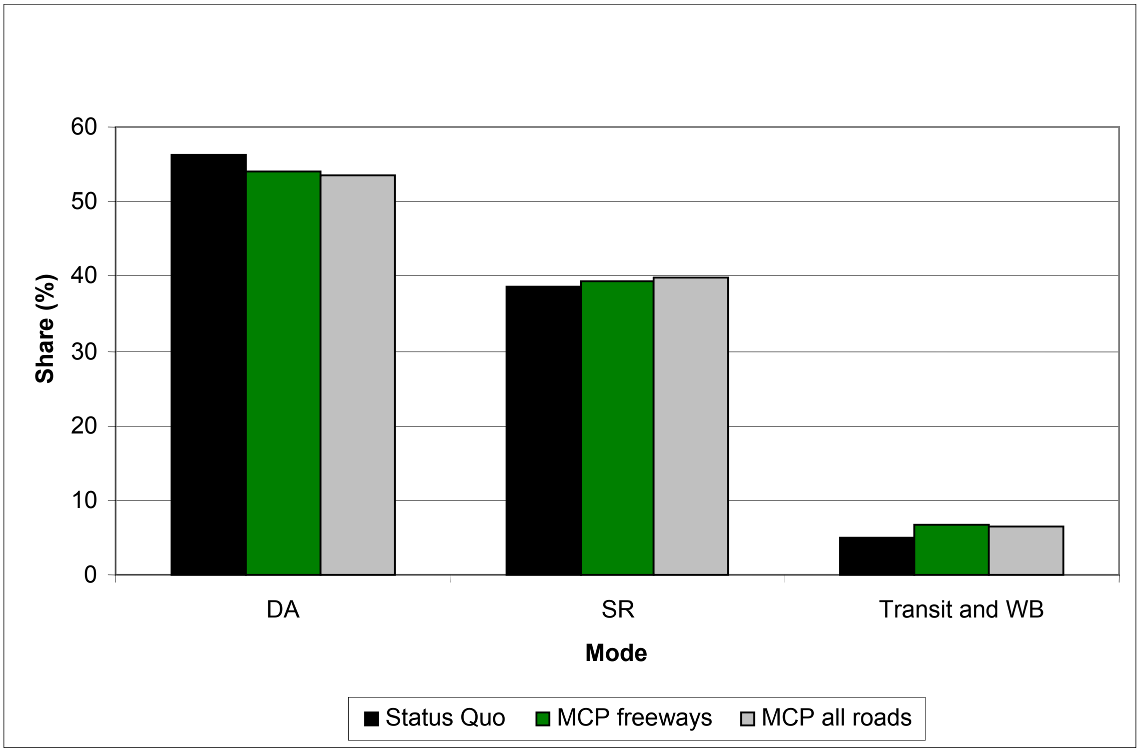

Figure E1.11: Mode shares in the peak-period (AM and PM peaks) (Long-term)

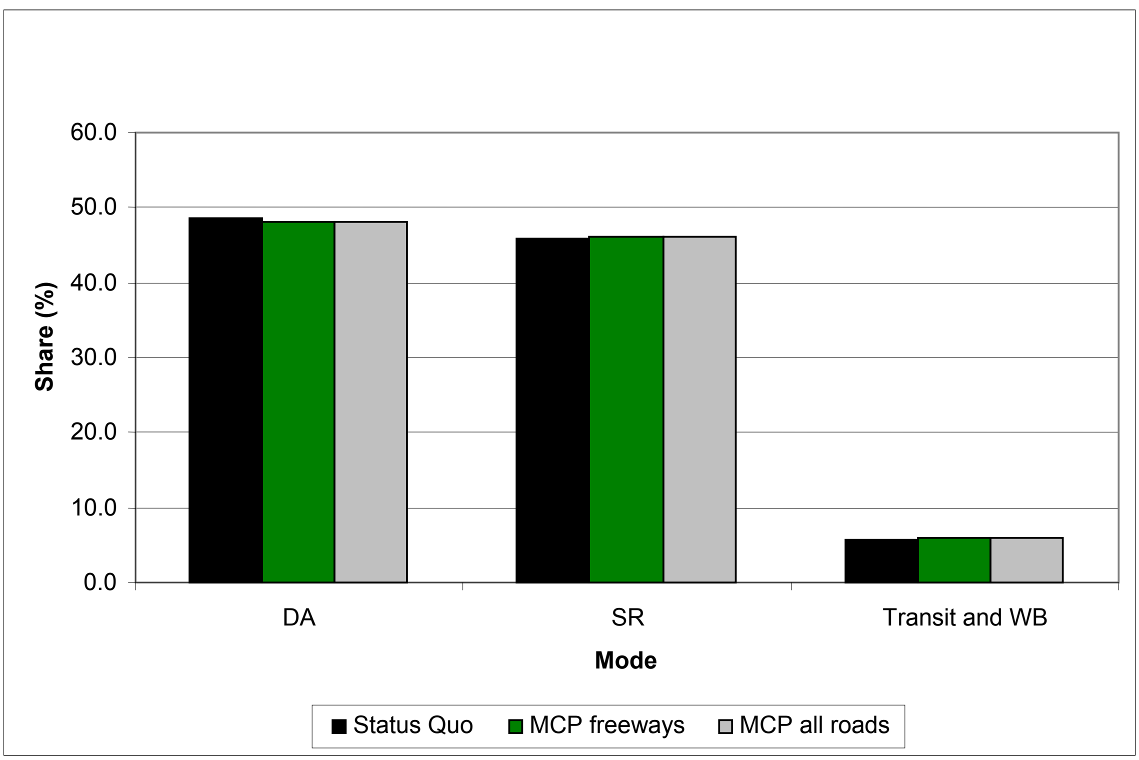

Figure E1.12: Mode shares in the day time off-peak period (Long-term)

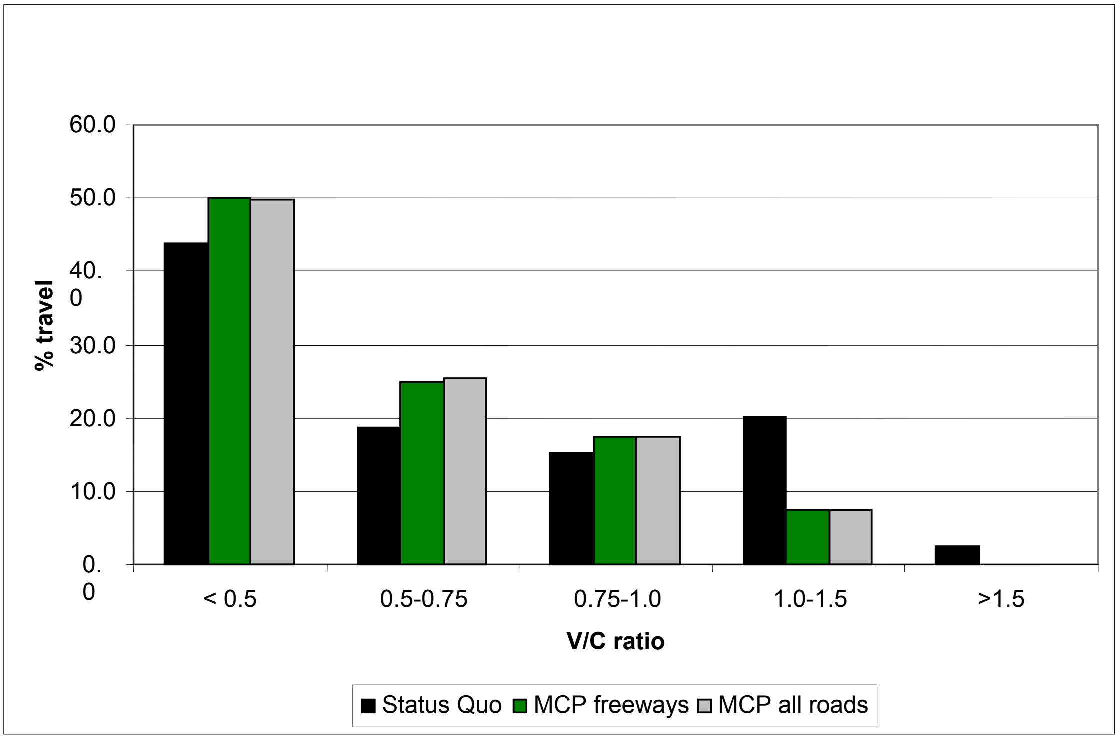

Figure E1.13: Percentage of daily travel at different V/C levels (Short-term)

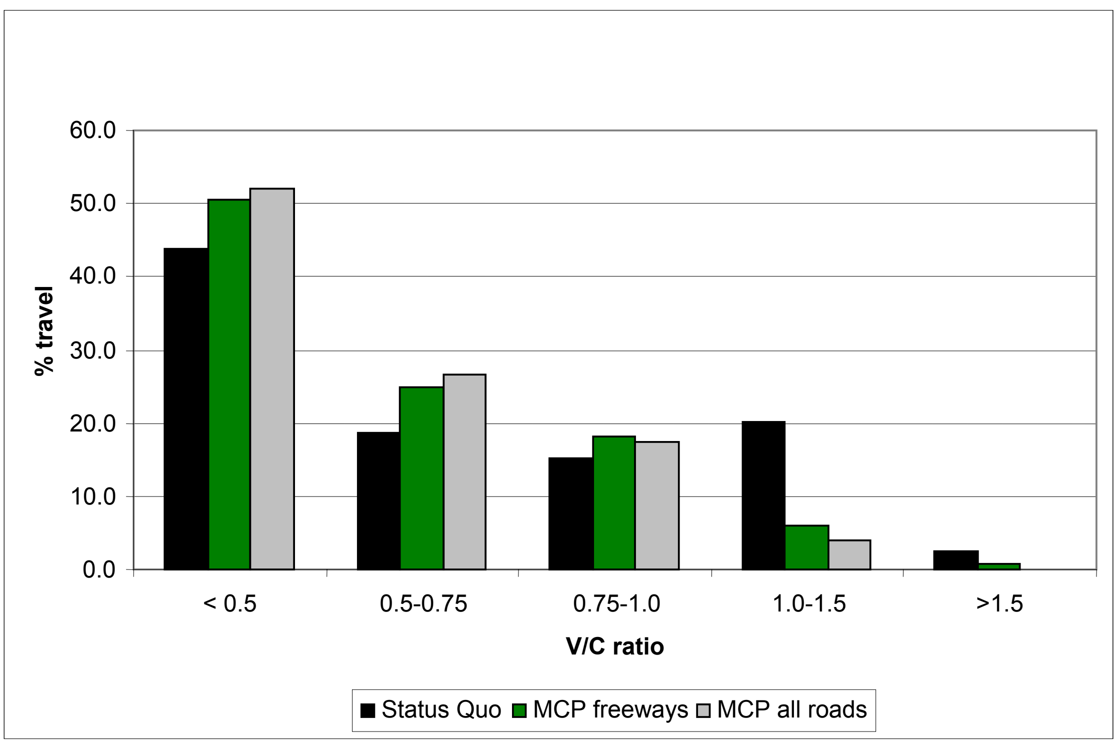

Figure E1.14: Percentage of daily travel at different V/C levels (Long-term)

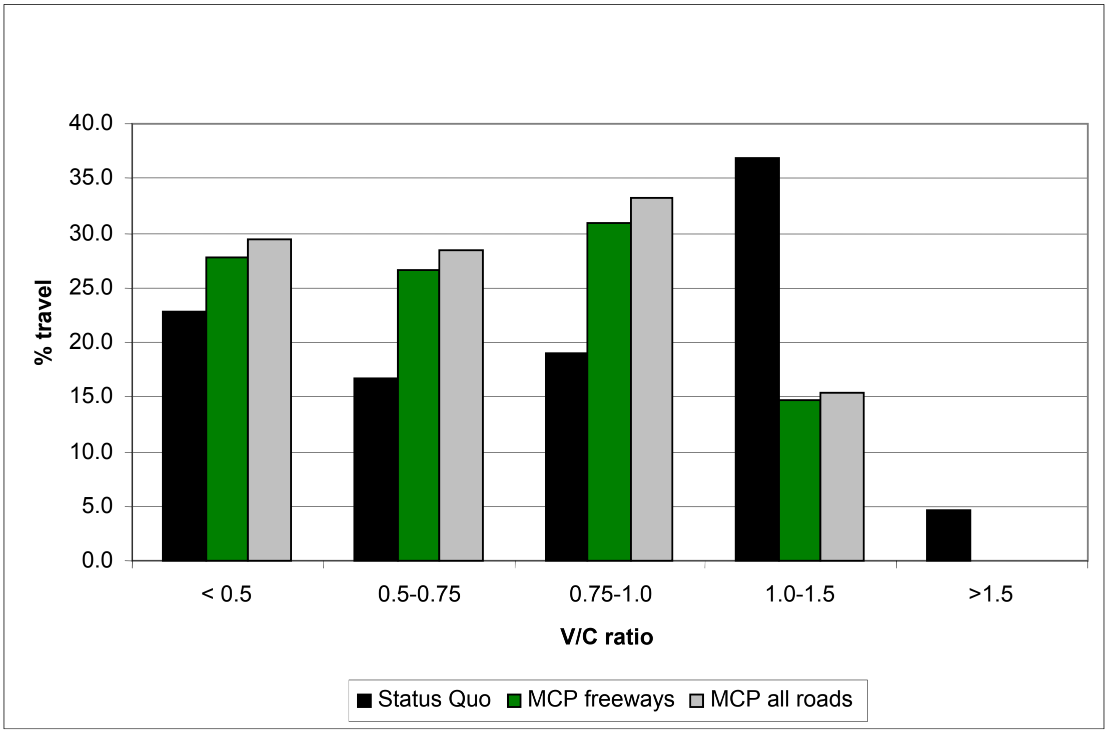

Figure E1.15: Percentage of peak-period travel (AM and PM peaks) at different V/C levels (Short-term)

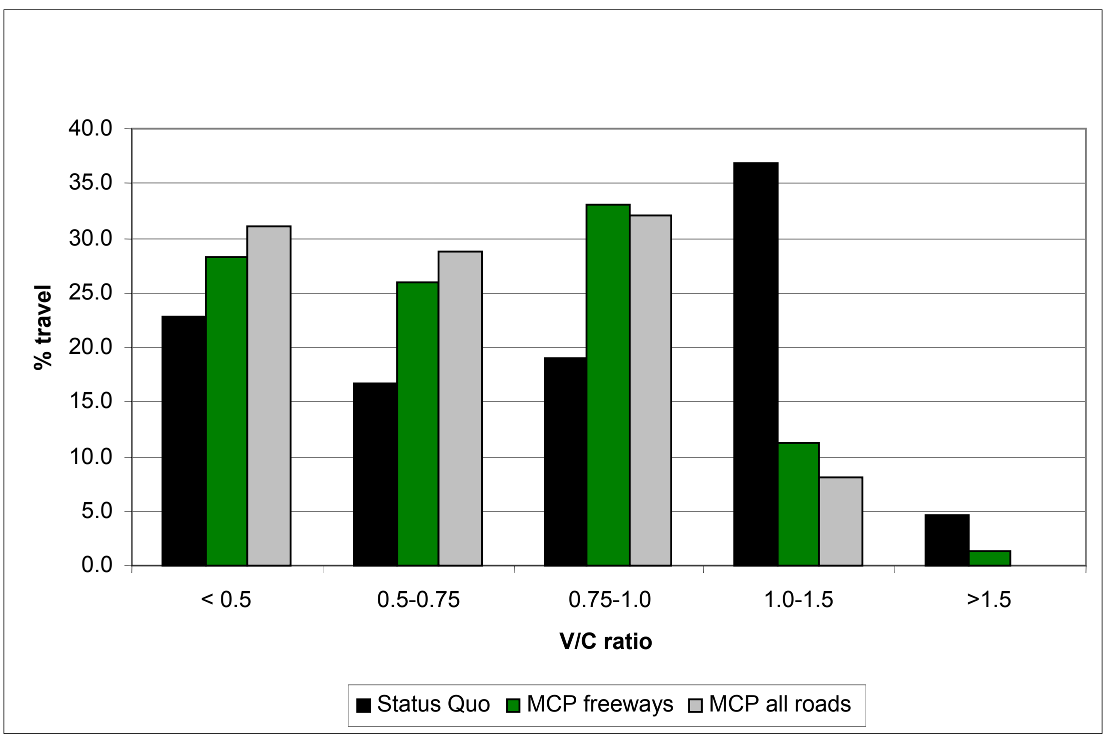

Figure E1.16: Percentage of peak-period travel (AM and PM peaks) at different V/C levels (Long-term)

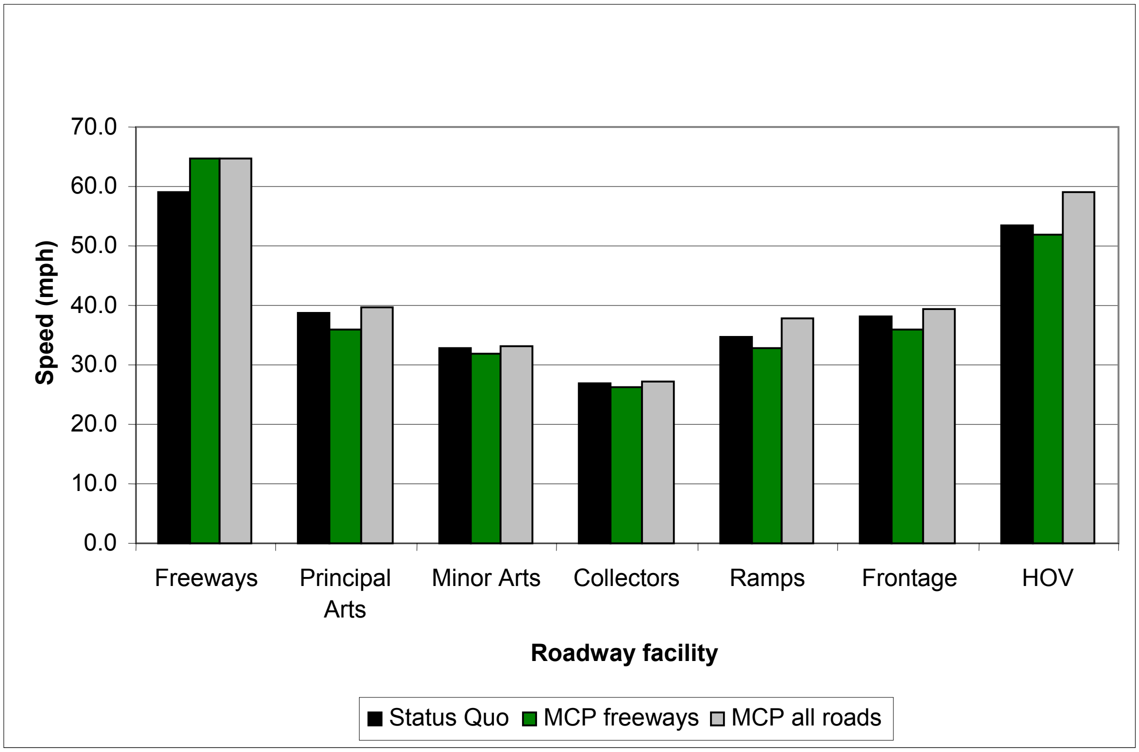

Figure E1.17: Average speed by roadway facility type (Short-term)

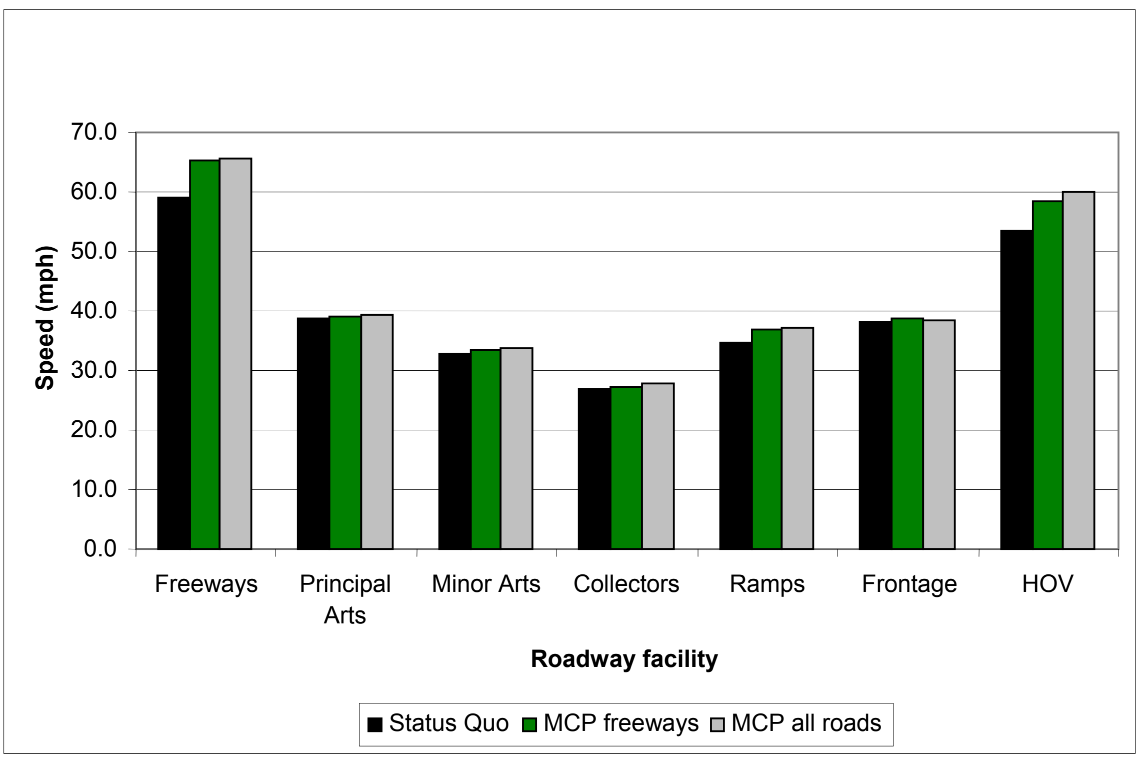

Figure E1.18: Average speed by roadway facility type (Long-term)

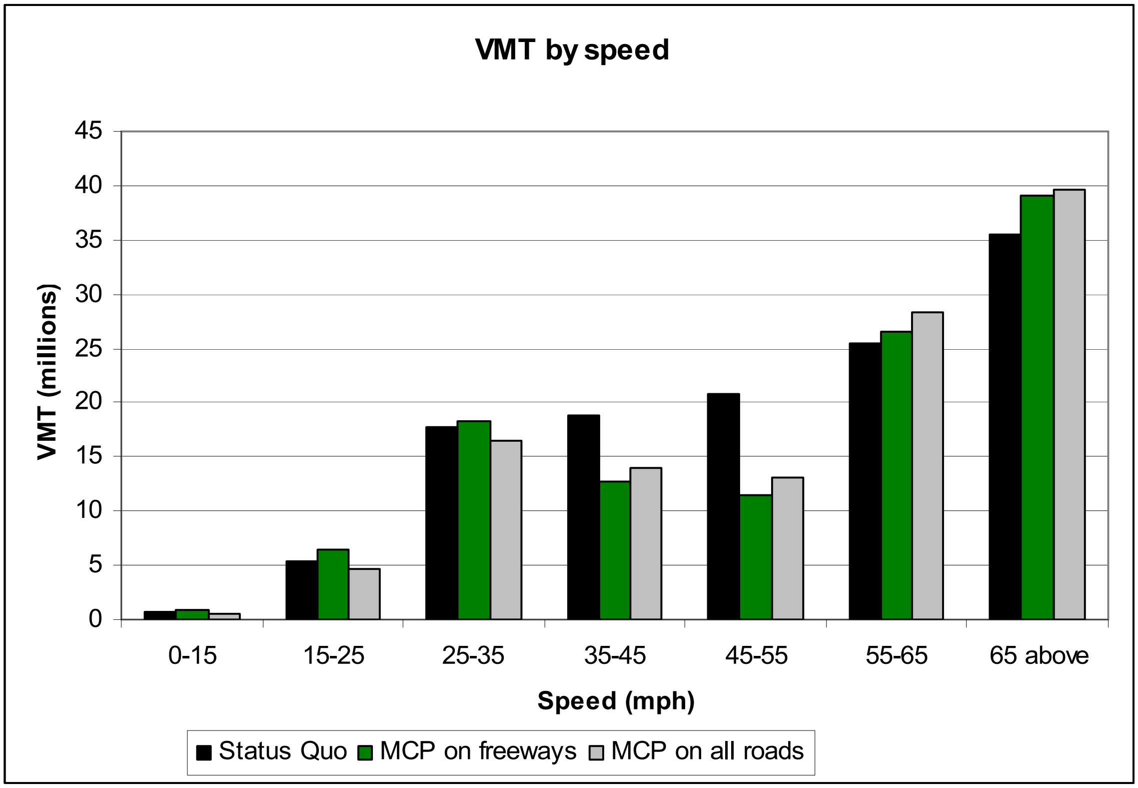

Figure E1.19: VMT by speed (Short-term)

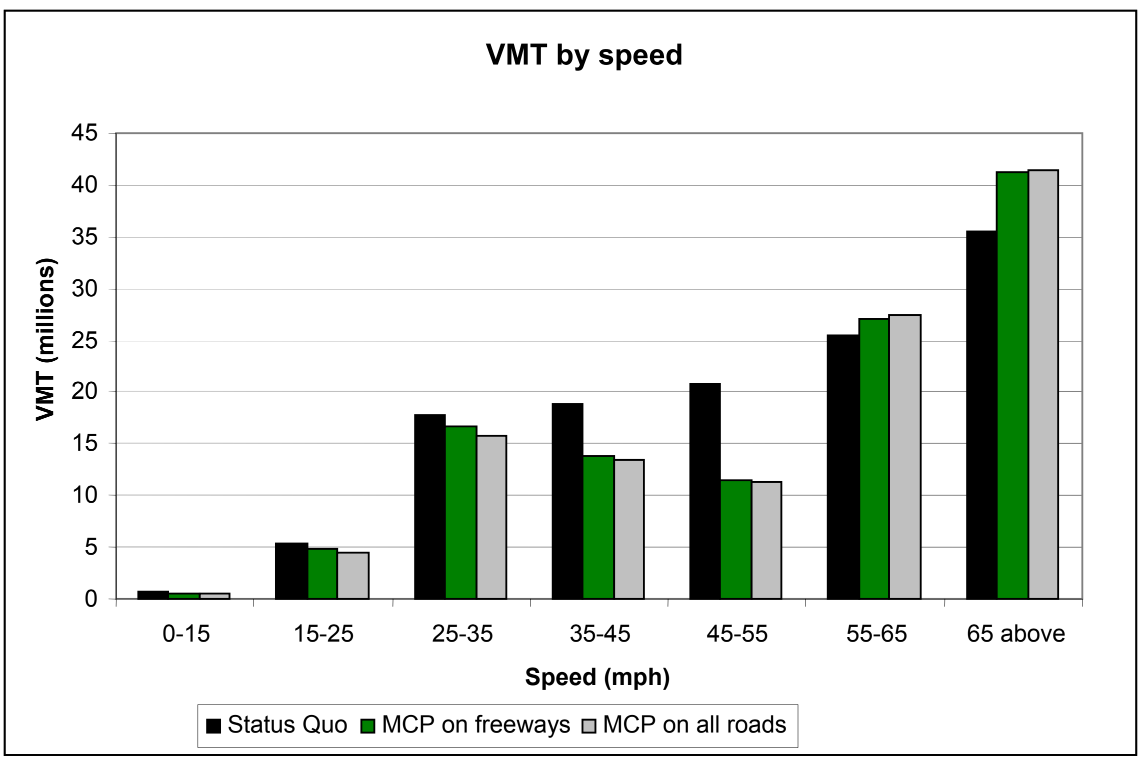

Figure E1.20: VMT by speed (Long-term)

A Comparison with NCTCOG's TDM Results

The results obtained from the TDM's application (status quo) were compared with those of NCTCOG's TDM. On the whole, the predicted VMT compared well, but the predicted speeds were considerably higher than those predicted by NCTCOG. Table E1.3 gives a comparison of the two studies.

Table E1.3: Comparison of current TDM results and NCTCOG's analysis

		Current study	NCTCOG
AM peak		6:00am-9:00am	6:30am-9:00am
	VMT/day	26,770,648	22,633,104
	% VMT at speeds>65mph	15.1%	9.3%
PM peak		3:30pm-7:00pm	3:00pm-6:30pm
	VMT/day	38,417,932	31,456,073
	% VMT at speeds>65mph	13.3%	9.4%
Off-peak		9:00 am-3:30pm 7:00pm-6:00am	9:00am-3:00pm 6:30pm-6:30am
	VMT/day	59,182,815	68,391,500
	% VMT at speeds>65mph	44.6%	17.7%
Daily Total	VMT/day	124,371,396	122,480,677
	% VMT at speeds>65mph	28.6%	13.9%

The total daily VMT compares well for the two studies. NCTCOG's AM peak VMT is less because its AM period is of shorter duration. (The choice of peak period was specified by the Texas Department of Transportation, the sponsors for research project 0-4634). The speeds, however, differ significantly. The average speed (total VMT/total VHT) for the AM peak period in the current study (for status quo) is 42.4 mph, while NCTCOG has an average AM peak speed of 33.0 mph. Also, as seen in final row of Table E1.2, a much larger percent of VMT is at higher speeds according to the current study (for example, 28.6 percent vs. 13.9 percent at speeds greater than 65 mph).

The main reason for this difference is due to the link performance functions which define the volume-delay relationship. This study used the standard BPR formulation, while NCTCOG used its own link performance function and then post-processed the speeds obtained from their traffic assignment so as to better match the observed speeds. Figure E1.21 gives speed as a function of V/C for the standard BPR. It also shows corresponding speeds for NCTCOG's link performance function and their post-processed speeds for a scenario with free flow speed of 60 mph.

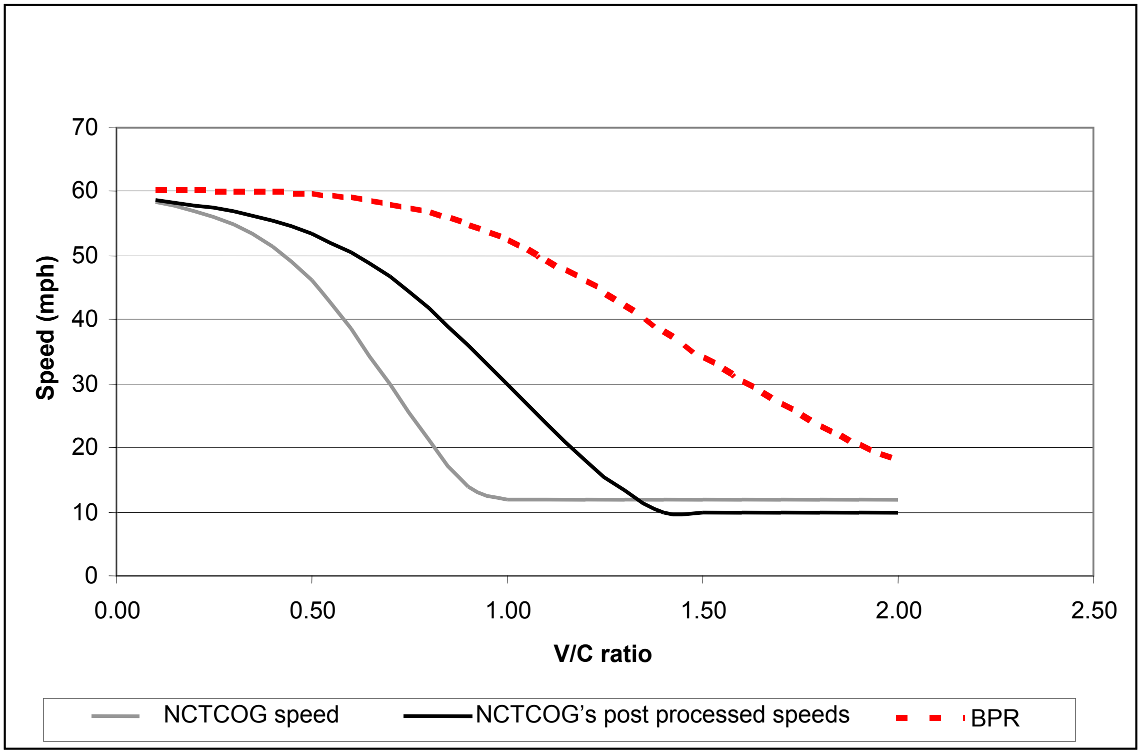

Figure E1.21: Speed as a function of V/C ratio (NCTCOG and standard BPR)

The percentage of VMT on different roadways types also differed for the two studies. The current study predicts a larger percentage of VMT on the freeways. This again might be due to NCTCOG's link performance function speeds falling sharply with an increase in link volume, when compared to the BPR formulation (see Figure E1.13). Table E1.4 gives VMT distribution by facility type as predicted by the two studies for the AM peak-period and the off-peak period.

Table E1.4: Comparison of percent VMT by roadway type

	AM peak VMT (%)		Off-peak VMT (%)	
	Current study	NCTCOG	Current Study	NCTCOG
Freeways	52.4	41.9	61.5	49.5
Principal arterials	16.3	16.2	13.8	16.2
Minor arterials	17.7	23.9	12.9	19.5
Collector streets	6.4	9.6	4.9	7.4
Ramps	3.5	3	4.0	3.3
Frontage roads	3.4	5	2.7	3.8
HOV	0.4	0.3	0.3	0.2

Limitations

One of the limitations of this analysis is that it does not allow flexibility in departure time choices across the five time periods. This choice could not be adequately modeled since transit trips in the on-board survey data did not have information regarding time of day. Also, since there were only two travel time and cost matrices (corresponding to peak and off-peak) to start with, departure time modeling was not reasonable or useful. However, users are not likely to change their departure times (leave earlier or later) across the five rather broad (3+ hour) time periods used in this study. Dynamic traffic assignment would have addressed this issue. Also, the traffic assignment was carried out using a single VOTT of $10.00/vehicle-hour. This value actually differs by user group and vehicle occupancy. In addition, it was not possible to incorporate all the potential long-term effects of MCP. Such effects may include land use changes, like relocation of households and jobs. Property value changes may also occur, resulting in greater or lesser welfare effects of such policies (as estimated in Chapter 7). Finally, the limitations of the joint DM choice models (see Chapter 4) and TDM application process (see Chapter 5) hold here as well.

Appendix E2: Welfare Changes

The objective of the current analysis is to identify neighborhoods and user groups that benefit and/or lose under a credit-based congestion pricing (CBCP) policy. The next section discusses the methodology adopted for computing such welfare changes. This is followed by a discussion of the results, across trip producing zones in the DFW region for different demographic groups. The implications for a CBCP policy (and limitations of the analysis) are discussed before concluding the chapter.

Methodology

In standard economics, consumer surplus (CS) is computed by evaluating the area under an individual's demand curve(s) (Varian, 1992). Ben-Akiva and Lerman (1985) use the following compensating variation (Small and Rosen, 1987) measure of CS, based on a discussion by Williams (1977):

$$\Delta CS_n = \sum_{j \in C_n} \int_{V_{old,n}}^{V_{new,n}} P(j \mid V) dV \qquad (1)$$

where j denotes the choice alternative and C_n denotes the choice set of individual n. Substituting the probability expression for the multinomial logit case, the above expression can be written as:

$$\Delta CS_n = \sum_{j \in C_n} \int_{V_{old,n}}^{V_{new,n}} \frac{\exp(V(j,n))}{\sum_{j \in C_n} \exp(V(j,n))} dV$$

$$\Delta CS_n = \ln\left[\sum_{i \in C_n} \exp(V_{new}(j,n))\right] - \ln\left[\sum_{i \in C_n} \exp(V_{old}(j,n))\right] \qquad (2)$$

which is the difference of the logsums of the two scenarios. This quantity is still in terms of utility and can converted to monetary units by dividing it by the marginal utility (MU) of money, $MU_{\$}$.

$$\Delta CS_n^{\$} = \frac{1}{MU_{\$}} \{ \ln\left[\sum_{i \in C_n} \exp(V_{new}(j,n))\right] - \ln\left[\sum_{i \in C_n} \exp(V_{old}(j,n))\right] \} \qquad (3)$$

The CS computations in this model's set-up are not so straightforward, however. First of all, and most importantly, the marginal utility of money is not constant in these models. Instead, expressions involving trip generalized costs were parameterized as a function of traveler demographics (6 categories of income and vehicle ownership information). This significantly improved the model fit of the DM choice model; however, it makes standard logsum welfare calculations (as in Kalmanje and Kockelman, 2004 and Gupta et al., 2005) impossible. In addition to this fundamental difference, each $\Delta CS_n^{\$}$ value differs by time of day. (Note: A time-of-day indicator is not shown in the following expressions for the sake of simplicity.)

In addition to these general issues, Equation 2's CS measure is not always applicable for work trips, since workers are not permitted to choose their employment location in the short-term.

Instead, $\Delta CS_{i,n}^{HBW}$ (for short-term HBW trips) is computed at production zone *i* for individual (user group) *n* as:

$$\Delta CS_{in}^{HBW} = \sum_{j \in C_j} \sum_{m \in C_{m,i}} P_{new}^{HBW}(i,j,m,n) V_{new}^{HBW}(i,j,m,n) - \sum_{j \in C_j} \sum_{m \in C_{m,i}} P_{old}^{HBW}(i,j,m,n) V_{old}^{HBW}(i,j,m,n) \quad (4)$$

where $V^{HBW}(i,j,m,n)$ is the systematic utility for an individual *n* residing in zone *i* and choosing destination *j* and mode *m*, and $P^{HBW}(i,j,m,n)$ is the corresponding probability (for HBW trips). Subscripts *new* and *old* indicate the after (MCP) and before (status quo) scenarios, respectively. C_j is the choice set of all destinations, and $C_{m,i}$ is the choice set of available modes for trip production zone *i*.

For HBNW trips the change in CS, $\Delta CS_{i,n}^{HBNW}$, is computed at production zone *i* for individual (user group) *n* similar to Equation 2, as follows:

$$\Delta CS_{in}^{HBNW} = \ln\left[\sum_{j \in C_j} \sum_{m \in C_{m,i}} \exp(V_{new}^{HBNW}(i,j,m,n))\right] - \ln\left[\sum_{j \in C_j} \sum_{m \in C_{m,i}} \exp(V_{old}^{HBNW}(i,j,m,n))\right] \quad (5)$$

The change in CS for non-home-based (NHB) trips is computed at the origin zone similar to Equation 6, the only difference being that the change in CS is the same for all user groups (since no demographic variables were used in the NHB trip choice models). Thus change in CS, ΔCS^{NHB}, is expressed as:

$$\Delta CS_{i}^{NHB} = \ln\left[\sum_{j \in C_j} \sum_{m \in C_{m,i}} \exp(V_{new}^{NHB}(i,j,m))\right] - \ln\left[\sum_{j \in C_j} \sum_{m \in C_{m,i}} \exp(V_{old}^{NHB}(i,j,m))\right] \quad (6)$$

where $V^{NHB}(i,j,m)$ is the systematic utility for an individual residing in zone *i* choosing destination *j* and mode *m* for NHB trips.

The $MU_\$$ is computed as the partial derivative of the systematic utility with respect to the cost variable, $\frac{\partial V}{\partial Cost}$. For the joint DM model specification (as discussed in Chapter 4), the $MU_\$$ is not constant. It varies with the generalized cost for the trip, with traveler demographics (i.e., user group), by trip purpose, and by trip production zone. For HBW and HBNW trips the $MU_\$$ for an individual residing in zone *i* choosing destination *j* and mode *m* is equal to:

$$MU_{\$_{ijmn}}^{trip} = \frac{\beta_{imped}^{trip}}{C_{ijm} + VOTT_n^{trip} * T_{ijm}} + \beta_{veh,m}^{trip} \delta_{vehown} \quad (7)$$

where β_{imped} is the coefficient on the logarithm of generalized cost, C_{ijm} and T_{ijm} are the travel cost and time, respectively, for travel from zone *i* to zone *j* using mode *m*, and $VOTT_n$ is the value of travel time for individual (user group) *n*. $\beta_{veh,m}$ is the coefficient on the vehicle ownership indicator and δ_{vehown} is the vehicle ownership indicator variable. The superscript *trip* refers to the trip type (HBW or HBNW).

The $MU_\$$ for NHB trips by an individual residing in zone *i* choosing destination *j* and mode *m* is equal to:

$$MU_{\$ijm}^{NHB} = \frac{\beta_{imped}^{NHB}}{C_{ijm} + VOTT^{NHB} * T_{ijm}} \tag{8}$$

where β_{imped}^{NHB} is the coefficient on the logarithm of generalized cost in the expression for systematic utility of NHB trips, and $VOTT^{NHB}$ is the value of travel time for NHB trips.

The change in expected maximum utility (under a CBCP policy) is computed for an individual residing in a specific trip production zone. However, the $MU_{\$ijmn}^{trip}$ value varies with each choice of destination *j* and mode *m* (in addition to the user group and trip production zone). Since the change in CS for a user group is computed at the TSZ level, a single value of $MU_{\$}$ corresponding to each TSZ (for each user group) is required to convert the change in CS to monetary units. So, an expected marginal utility of money $MU_{\$ijmn}^{trip}$ across all destination-mode choices for individual *n* in production zone *i*, is computed. This is done by following expression:

$$MU_{\$in}^{trip} = \sum_{j \in C_j} \sum_{m \in C_m} P^{trip}(i,j,m,n) MU_{\$ijmn}^{trip} \tag{9}$$

where the value of $MU_{\$ijmn}^{trip}$ is obtained from Equations 7 and 8 for different trip purposes. This value differs by user group for HBW and HBNW trips but is constant across all user groups for NHB trips. Since the $MU_{\$}$ differs for the old and new scenarios, an average value was assumed.

$$MU_{\$in}^{trip} = \frac{1}{2}\left[MU_{\$in,new}^{trip} + MU_{\$in,old}^{trip}\right] \tag{10}$$

where the $MU_{\$in,new}^{trip}$ and $MU_{\$in,old}^{trip}$ values are computed as in Equation 9 (corresponding to the new and old scenarios, respectively). The idea is to compute the change in CS (in utility terms) accurately and convert it to monetary units using an approximate value of marginal utility of money (obtained using approximate procedures). The change in CS for at production zone *i* for individual (user group) *n* can be expressed in monetary units as:

$$\Delta CS_{in}^{trip,\$} = \frac{\Delta CS_{in}^{trip}}{MU_{\$in}^{trip}} \tag{11}$$

This value differs across user groups for HBW and HBNW trips, but is the same for NHB trip makers. The change in CS for NHB trips is calculated at the origin zone level, and is averaged across all zones.

$$\Delta CS^{NHB,\$} = \frac{1}{\#origins} \sum_{i \in C_i} \Delta CS_i^{NHB,\$} \tag{12}$$

where *#origins* is the number of origin zones (4813) and C_i is the set of all origin zones.

The values of change in CS as given by Equations 11 and 12 vary by time of day. So, a single value $\Delta CS_{in,day}^{trip,\$}$ is computed as:

$$\Delta CS_{in,day}^{trip,\$} = \sum_{t \in C_t} \lambda_t^{trip} \Delta CS_{in,t}^{trip,\$} \tag{13}$$

where $\Delta CS_{in,t}^{trip,\$}$ is the change in CS for a particular trip type for individual (user group) *n* at production zone *i* in time period *t*, λ_t^{trip} is the fraction of trips of a particular trip type in time period *t*, and C_t is the set of five time periods (see Table D2.1).

The daily change in CS depends on the number of trips made in a day. An average individual makes 0.9 HBW trips, 1.8 HBNW trips, and 0.83 NHB trips on a weekday (according to the 1996 DFW household survey). Also included in overall traveler welfare change is the CBCP travel budget, $BUDGET_{in,day}$ (which could differ across user groups and location depending on the particular flavor of CBCP policy selected). This analysis assumes a constant rebate budget for every registered vehicle owner. The net monthly revenue from MCP-on-freeways is predicted to be \$30.6 million. The total number of vehicles in DFW region is estimated to be around 3 million. Each household owns 1.9 vehicles on average. Assuming that 30 percent of vehicles have owners registered for a second vehicle, there may only be 2.1 million people eligible for a travel budget (assuming there are no additional budget eligibility criteria). And, each eligible user would get a budget of \$14.60. Alternatively, CBCP could be designed so that only commuters using freeways receive travel budgets. There are 3.97 million home-based work trips in the DFW region each day and 3 million jobs. If 90 percent of these jobs' commuters (2.7 million persons) are considered eligible for a travel budget, each would get a \$11.30 monthly budget. The welfare computations assume a monthly budget of \$15.00, which translates to \$0.68 per weekday. These computations account for use of some revenues for program administration and capital costs and are discussed in much more detail in Chapter 9.

Overall then, with budgets included, the daily change in CS for individual (user group) *n* at trip production zone *i* is estimated as:

$$\Delta CS_{in,day}^{total,\$} = 0.9\Delta CS_{in,day}^{HBW,\$} + 1.8\Delta CS_{in,day}^{HBNW,\$} + 0.83\Delta CS_{day}^{NHB,\$} + BUDGET_{in,day} \qquad (14)$$

Implementation of radio-based MCP-on-all-roads will require many roadside readers, so that scenario's implementation costs may exceed CBCP revenues. Equation 14's change in traveler welfare estimate is a holistic measure of travel benefits and differs across locations and user groups – and specific travel patterns. The following section discusses the change in CS across user groups and locations for status quo to MCP-on-freeways scenario.

Welfare Changes

As expected, welfare changes (including CBCP budget) were positive for many user groups and certain locations (winners) but negative for others (losers). The analysis considered the same three income categories that were used in the joint DM choice model:

- Low income: \$29,999 or less
- Medium income: \$30,000 – \$74,999
- High income: \$75,000 and higher

As discussed in Chapter 4, vehicle ownership (VO) information was available as an indicator variable (equal to 0 if the number of vehicles in the household was less than the household size and 1 otherwise). Thus, welfare changes were computed as a change from the status quo to a MCP-on-freeways scenario for the following six user groups.

- L0: Low income and VO indicator = 0
- L1: Low income and VO indicator = 1

- M0: Medium income and VO indicator = 0
- M1: Medium income and VO indicator = 1
- H0: High income and VO indicator = 0
- H1: High income and VO indicator = 1

Figures E2.1 through E2.6 illustrate the spatial distribution of daily CS change estimates for LO, L1, M0, M1, H0, and H1 user groups, respectively, for the MCP-on-freeways scenario. The welfare gains are represented in the same four categories in all the figures to facilitate comparison. Regions shaded black and dark grey indicate “losers”, with a welfare loss of greater than 25¢ and 0-25¢, respectively. Regions shaded light grey and white indicate “winners”, with a welfare gain of 0-35¢ and greater than 35¢, respectively. Also, the region’s freeways are highlighted.

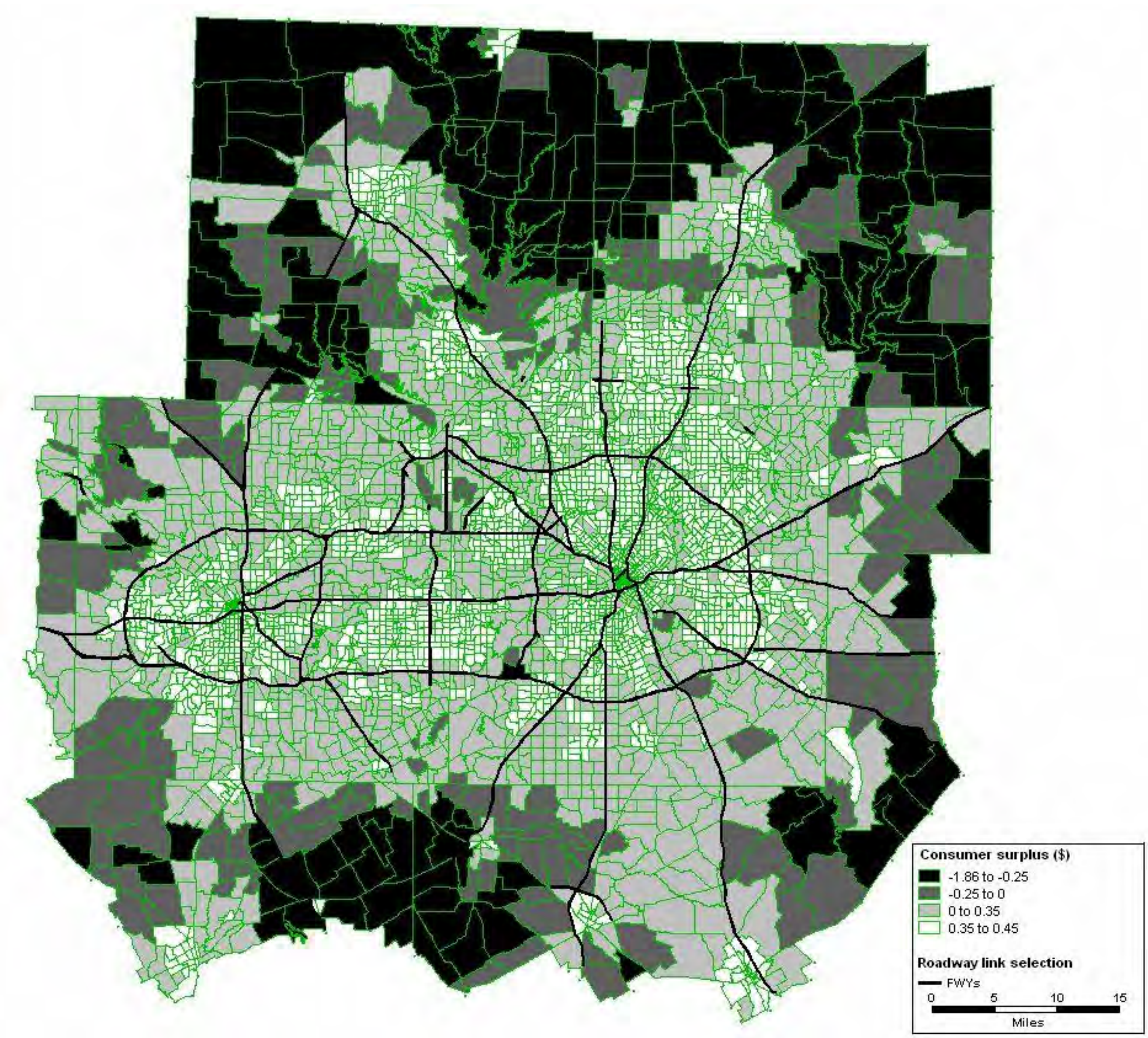

Figure E2.1: Welfare changes for low income and low vehicle ownership group (LO) for CBCP with freeways priced, after budgets returned

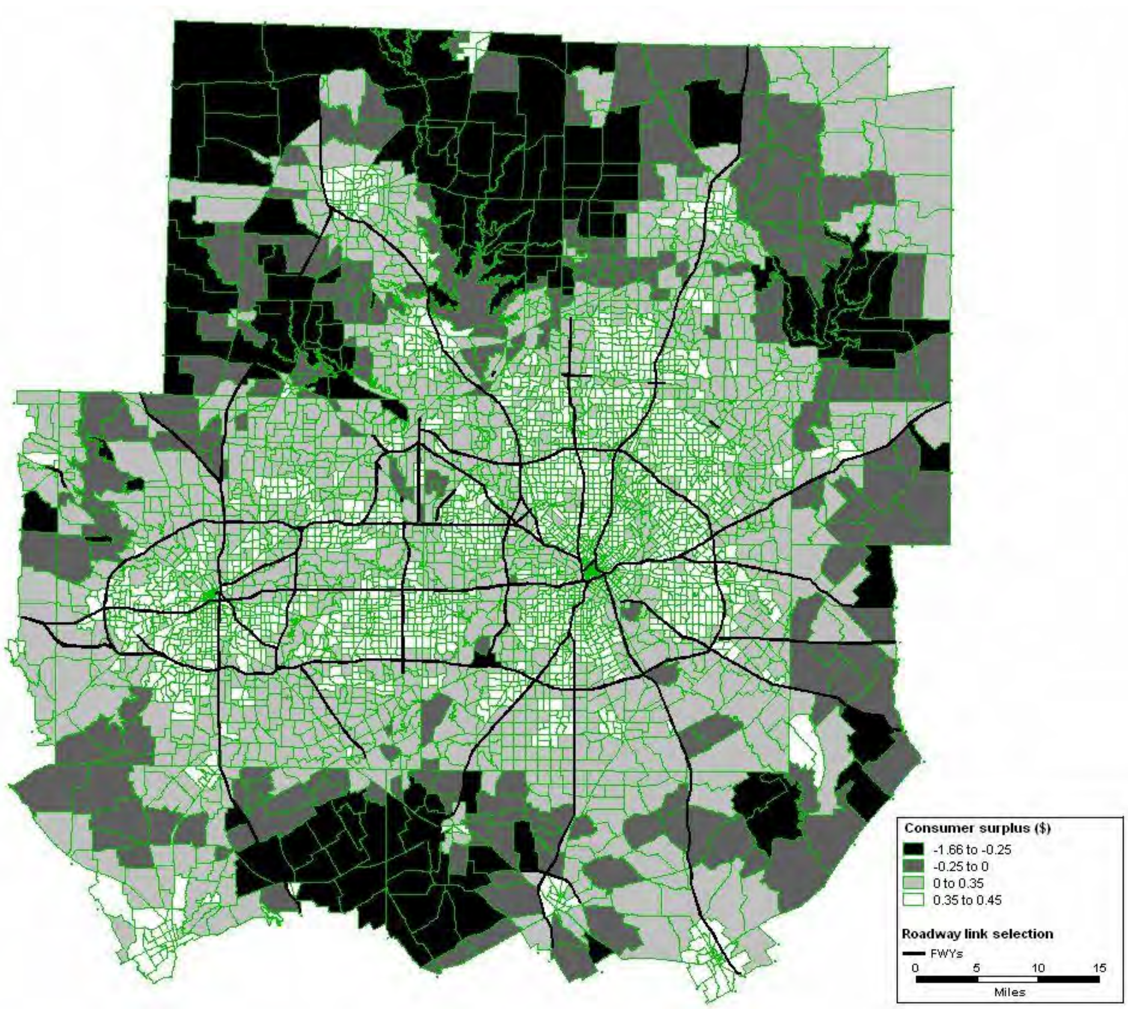

Figure E2.2: Welfare changes for low income and high vehicle ownership group (L1) for CBCP with freeways priced, after budgets returned

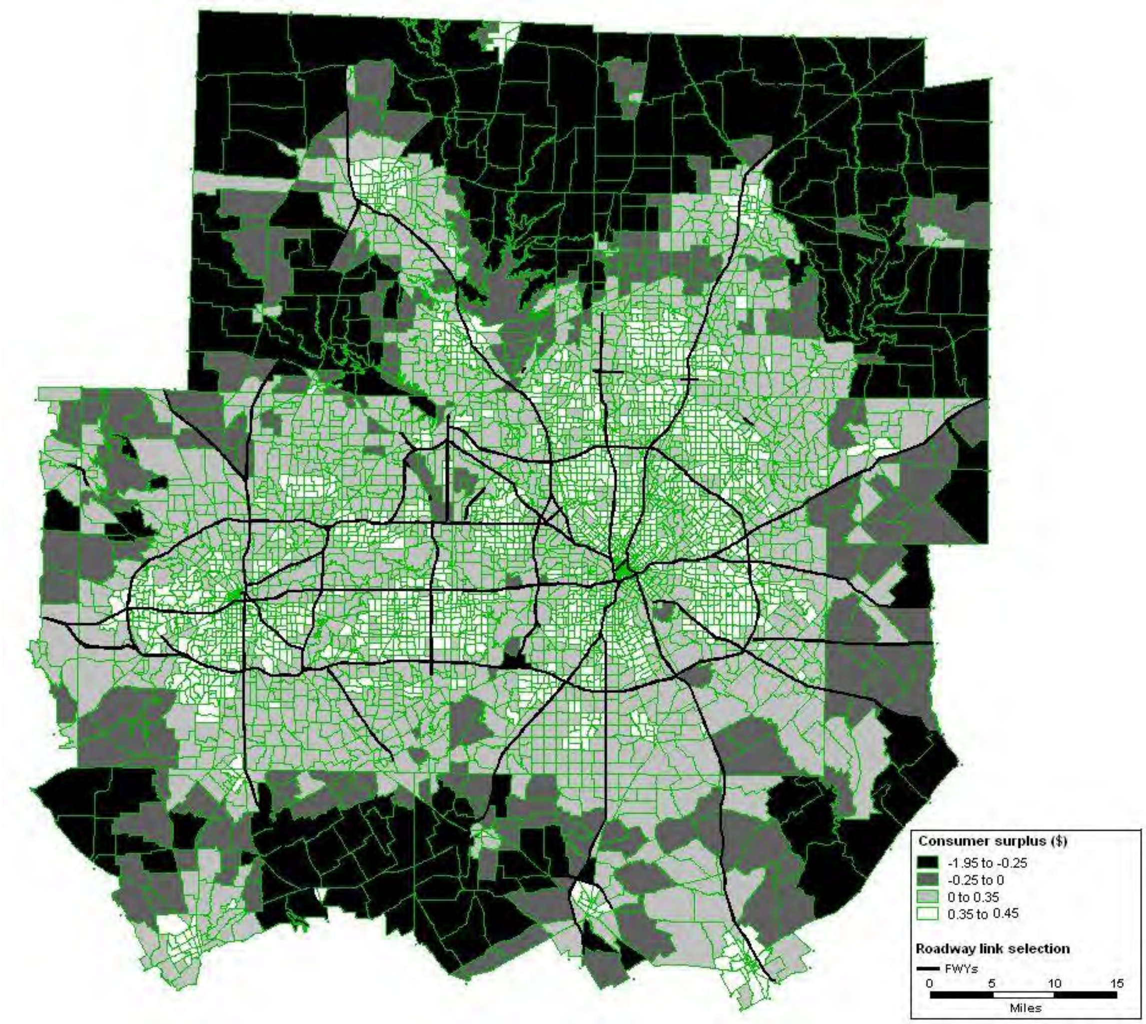

Figure E2.3: Welfare changes for medium income and low vehicle ownership group (MO) for CBCP with freeways priced, after budgets returned

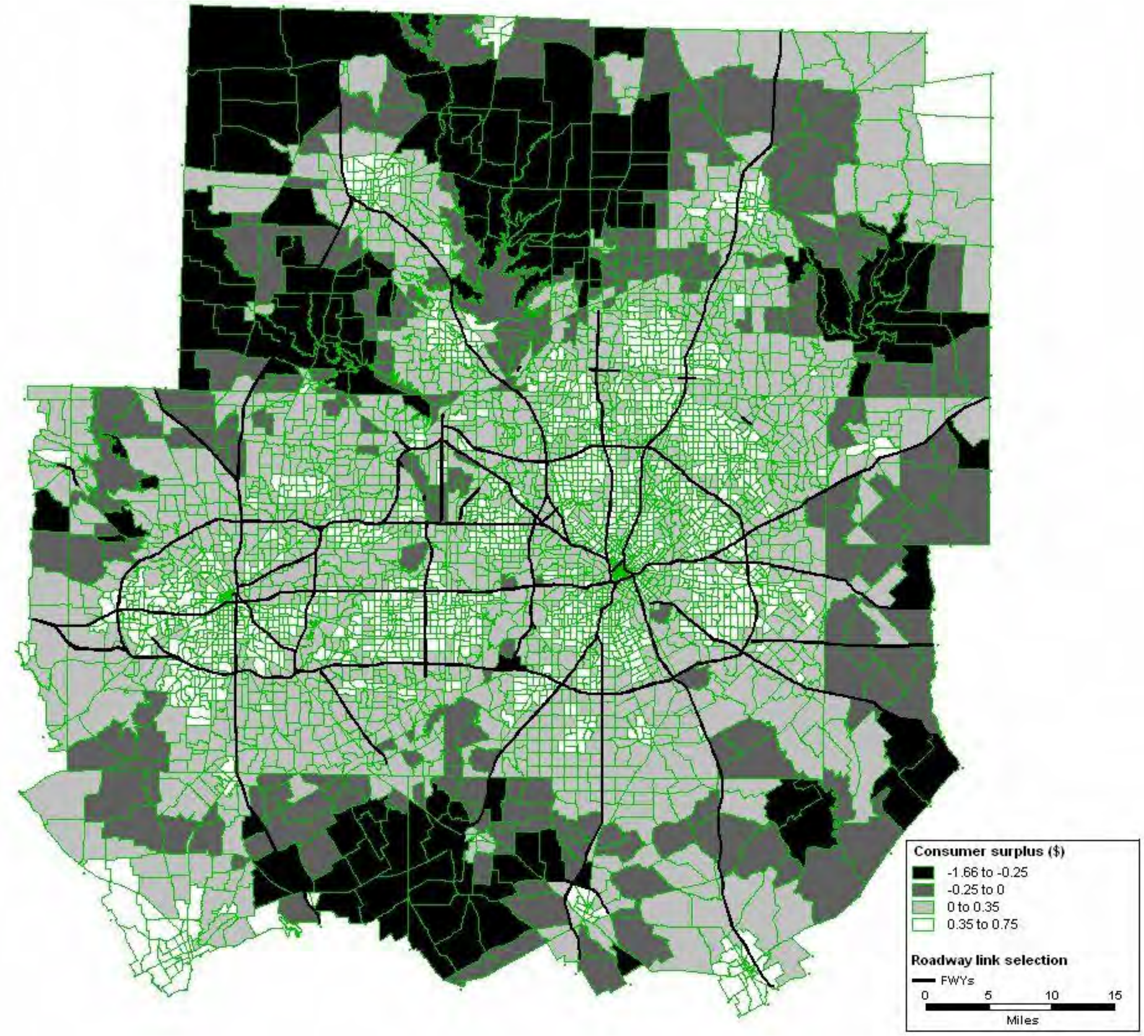

Figure E2.4: Welfare changes for medium income and high vehicle ownership group (M1) for CBCP with freeways priced, after budgets returned

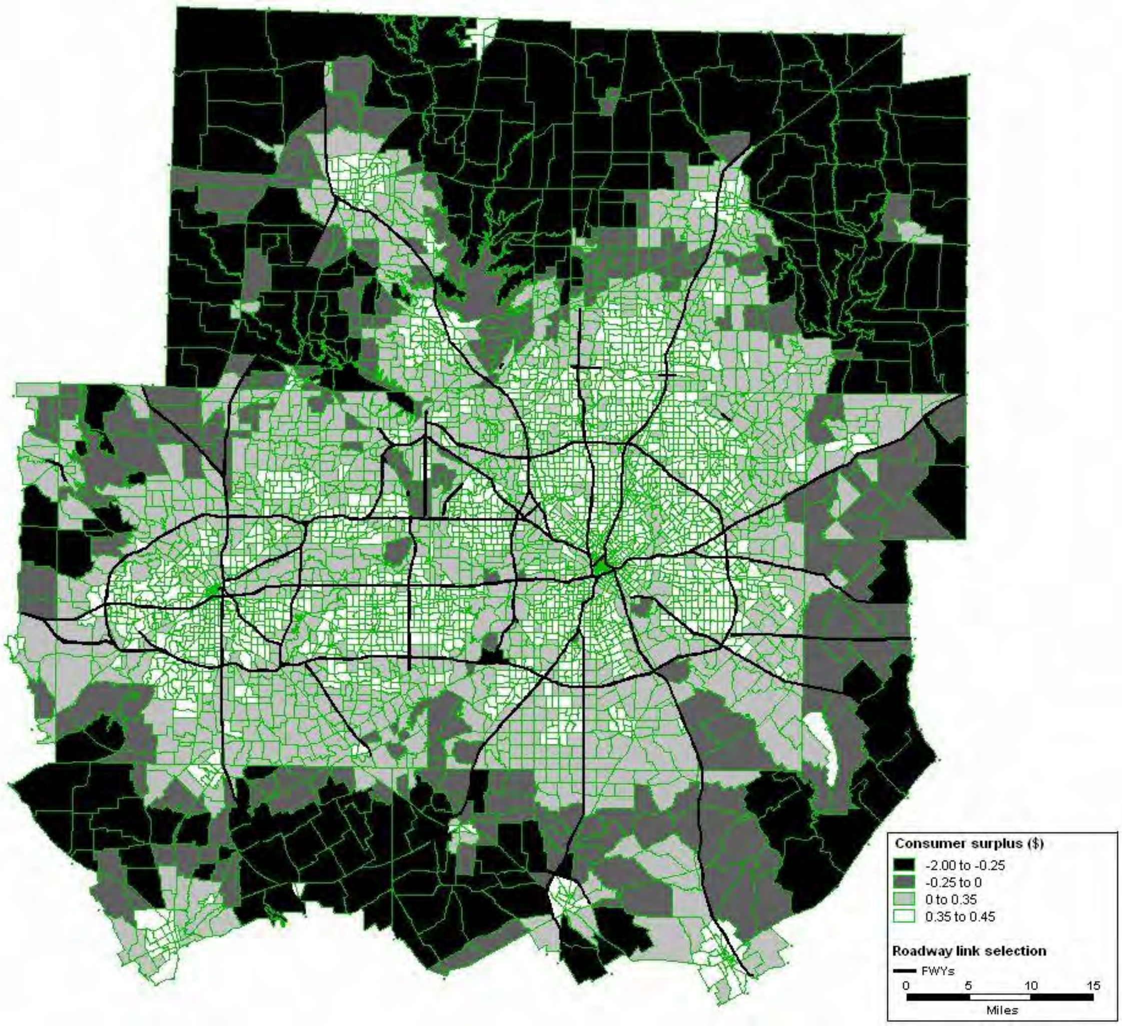

Figure E2.5: Welfare changes for high income and low vehicle ownership group (HO) for CBCP with freeways priced, after budgets returned

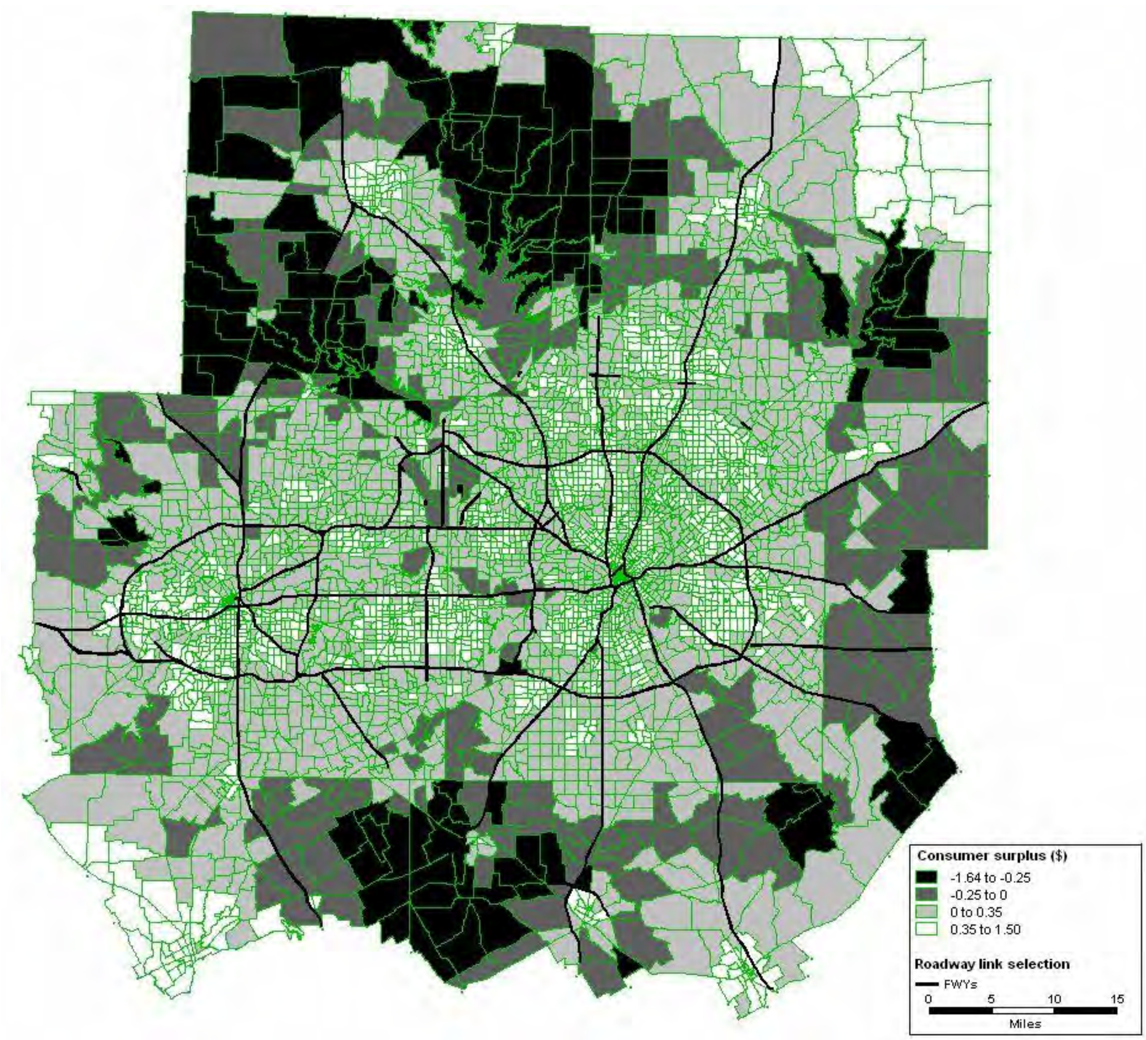

Figure E2.6: Welfare changes for high income and high vehicle ownership group (H1) for CBCP with freeways priced, after budgets returned

Figures E2.1 through E2.6 (for MCP-on-freeways scenario) clearly indicate that users near both the central business districts (CBDs) and all smaller city centers are the potential “winners”. In general, the welfare gain is the highest for users near the CBDs and drops as we move away from the CBDs. This is better illustrated in Figure E2.7 which shows approximate overall welfare contours for a CBCP policy. The regions with maximum welfare gain (greater than about 35¢/day) are not shaded (as in zones 1 through 11 in Figure E2.7). The lightly shaded regions (e.g., zone 12) show up next in the list of “winners” (0-35¢/day). The medium shaded regions (e.g., zone 13) lose less than 25¢/day, while the dark shaded regions (e.g., zone 14) lost most (more than 25¢/day). Users in the striped regions (e.g., zone 15) gain or lose depending on their vehicle occupancy. In general, the geographical distribution of welfare changes does not differ much across user groups. This is discussed in further detail in the next paragraph. It is interesting to note that zones 1 through 11 are all CBDs or city centers, as mentioned in Table E2.1.

Figure E2.7: Contours for welfare changes for MCP scenarios

Table E2.1: CBD/City center coding for Figure E2.7

Zone	CBD/City center of	Zone	CBD/City center of
1	Dallas	7	Fort Worth
2	Richardson	8	Arlington
3	Plano	9	Cleburne
4	McKinney	10	Waxahachie
5	Carrollton	11	Ennis
6	Denton		

Users, eligible for a travel budget, in and around the CBDs typically gain about 40¢/day. This suggests increased accessibility for the CBDs thanks to MCP with travel budgets for most vehicle owners or workers using freeways. (These are two reasonable eligibility criteria for one to receive travel budgets, as discussed earlier, and in detail Chapter 9.) Residents in the northern part of the DFW metropolitan statistical area (excluding the Denton and McKinney CBDs) are the most prominent "losers". The northwest regions (to the immediate west of Carrollton) also lose. Southern regions (between Cleburne and Waxahachie) also figure in the list of "losers". Even though they are assumed to receive a travel budget, average users are estimated to suffer a travel loss on the order of about 30¢/day in these regions.

As discussed earlier in this chapter, the analysis assumes travel budgets only for 70 percent of the vehicles. So, over 30 percent of the driving population is not eligible for a travel budget, and almost all the budget-ineligible drivers are predicted to lose (20-85¢ per weekday, depending on their location). In addition, not everyone is the "average traveler." Some make more trips each day, some fewer. Some drive more, some less. Some have higher values of travel time, others less. The discussion hereon, unless specified, pertains to registered budget-eligible "average" travelers only.

Vehicle ownership seems to be a governing factor for welfare changes in the northeast region of the DFW metroplex (further northeast of Plano). In general, households with more than (or exactly) one vehicle per person (VO=1, i.e., L1, M1, and H1) gained in the northeast, while those with less than one vehicle per person (VO=0, i.e., L0, M0, and H0) lost. Similarly, in the southwest region (to the immediate north of Cleburne) the L1, M1, and H1 households were estimated to be slightly well off than their L0, M0, and H0 counterparts. This trend is predicted for all income groups. All user groups in and around the CBDs were estimated to be "winners". However, in regions away from the CBD the higher income user categories (and VO=0) were predicted to lose more than the corresponding low income categories (and VO=0). In the northeast and southwest the higher income categories (and VO=1) are predicted to benefit more from CBCP than the lower income categories (and VO=1). This can be expected since $MU_{\$}$ is lower for high income user groups. ($MU_{\$}$ is inversely proportional to value of travel time, as given by Equations 7 and 8). A given change in utility would translate to a higher monetary value for higher income user groups. In other words, a particular change in consumer surplus would translate to a higher gain/loss for the higher income user groups compared to the lower income groups.

Interestingly, in all Figures (E2.1 through E2.6) the region's peripheral zones are shown as losers while those in the interior are better off. This may largely be simply an "edge effect", due to neglect of travel to zones outside the 9-county region. The TDM effectively requires that people residing and working on these metroplex edges travel longer distances than they probably do – and more than the average traveler. In this way, the CBCP budget is less likely to offset their predicted travel cost increases when MCP is implemented. Of course, the edge population is not as constrained as the map suggests. In reality, these are contiguous regions with many trip-making opportunities just beyond the region neglected in the TDMs. In addition, external attraction zones are neglected in the welfare computations. So, the edge population could be quite a bit better off than what is predicted by these welfare computations and shown in these figures.

Though not shown here the geographical distribution of the welfare impacts for an MCP on-all-roads scenario is similar to that of the MCP-on-freeways scenario (Figures E2.1 through E2.6, respectively). If revenues were sufficient to return the same $15.00/month travel budget to all eligible parties, the general findings discussed above for the MCP-on-freeways scenario would hold true for the MCP-on-all-roads scenario. However, the welfare gains would be predicted to be greater, as suggested by Table E2.2 (which gives the welfare gains for individuals in different user groups for both pricing scenarios – assuming a $15.00/month budget, which is probably only viable for the MCP-on-freeways scenario, since the implementation costs of MCP-on-all-roadways may leave little for travel budgets). The percentiles (in Table E2.2) indicate the order of welfare changes for different locations.

Table E2.2: Welfare changes ($/day) for different user groups

User group	Percentile						
	5	10	25	50	75	90	95
MCP-on-freeways							
L0	-0.15	0.05	0.27	0.37	0.40	0.42	0.43
L1	-0.11	0.06	0.27	0.36	0.40	0.42	0.43
M0	-0.21	0.01	0.24	0.35	0.39	0.41	0.43
M1	-0.14	0.03	0.24	0.35	0.39	0.41	0.43
H0	-0.26	-0.03	0.22	0.34	0.38	0.41	0.42
H1	-0.14	0.02	0.23	0.34	0.38	0.41	0.43
MCP-on-all-roads							
L0	-0.10	0.09	0.30	0.39	0.42	0.44	0.45
L1	-0.08	0.09	0.29	0.39	0.42	0.44	0.45
M0	-0.15	0.05	0.27	0.37	0.41	0.43	0.44
M1	-0.10	0.06	0.27	0.37	0.41	0.43	0.45
H0	-0.20	0.02	0.26	0.36	0.40	0.43	0.44
H1	-0.11	0.05	0.25	0.36	0.40	0.43	0.44

Note: This table assumes that the MCP-on-all-roads scenario enjoys the same $15.00/month travel budget that the MCP-on-freeways (-only) scenario is predicted and assumed to enjoy. In reality, this is not likely to be the case (due to higher implementation costs for an all-roads scenario). Moreover, both scenarios assume that the budget-eligible population is equal to 70 percent of the region's total number of vehicles (for purposes of calculating this travel budget). Finally, the losses may be offset by extending the region's boundaries to remove the "edge effect" discussed for peripheral zones.

For the MCP-on-all-roads scenarios, the welfare gain contours extend slightly further (away from the CBDs) than those obtained for the MCP-on-freeways scenarios. This indicates enhanced accessibility, primarily due to congestion relief on the principal arterials. However, the reader should note that, while pricing all roads, it may not be possible in the near future to provide similar travel budget as that of MCP-on-freeways alone, which is what this analysis assumes.

Implications for a CBCP policy

The spatial distribution of welfare changes across different user groups under a CBCP policy has important implications. If a differential budget allocation system is advocated, welfare change predictions can be used to evaluate different allocations. The analysis indicates that location matters. Eligible users north DFW (excluding regions around Denton and McKinney CBDs) could be given larger budgets to offset their potential losses. Eligible users in south DFW (between Cleburne and Waxahachie) might also be considered for higher budgets. Income-based budget allocation might not be required, since the high income users do not benefit much more when compared to the lower income users.

Alternatively, if differential budget allocation is not possible and not all revenue is returned to the users, some revenues could be devoted to regions losing most (dark shaded regions in Figure E2.8). This could be used in several indirect ways of compensation (as discussed in Chapter 3). On the whole, as indicated by Table E2.2, a majority of the TSZs are predicted to gain from a CBCP policy when considering average travel patterns and budgets. In terms of land area, just about 50 to 65 percent of the DFW metropolitan statistical area gains from a CBCP policy (differs by user group). However, this region has about 95 percent of the DFW population (and about 97 percent of the region's jobs). So, a majority of the population experiences travel benefits from the CBCP policy as suggested by the welfare changes.

Assumptions and Limitations

Many assumptions are required to compute the welfare numbers that are discussed in this chapter. The resulting welfare values are, of course, estimates. Moreover, after controlling for home location and some effects of vehicle ownership and household income, these welfare values are for the region's "average traveler." In reality, there is expected to be wide variation among travel patterns. The TDM's travel behavior predictions are estimates, as are the systematic utility expressions. Moreover, the $MU_\$$ values vary by choice, so a probability-weighted average value of $MU_\$$ had to be used. The welfare computations include a travel budget term (68¢/weekday per eligible traveler), which is somewhat uncertain. It depends on project implementation costs (which are estimated conservatively in Chapter 9) and revenue distribution (traveler eligibility is assumed to be restricted to about 2.1 million persons).

Also, the tolls charged and route choices are based on a higher VOTT ($10.00/hour) than those assumed in the DM choice models (see Table D1.4). This results in higher tolls – and greater congestion relief (and thus traffic impacts). However, since the welfare calculations are based on lower VOTTs ($5.00-$10.00/hour), predicted welfare gains are expected to be lower than actual gains. However, not everyone may receive a travel budget. The lack of such a budget may well result in negative impacts for various traveler types. Figures E2.1 through E2.6 suggest losses for the population residing on the edges of the map. However, the population is not as constrained as the map suggests. In reality, these are contiguous regions with many trip-making opportunities just beyond the region neglected in the TDMs. In addition, welfare computations neglect external attraction zones. So, the edge population could be quite a bit better off than what is predicted by these computations.

Appendix F: Emissions Estimation

Methodology for Emissions Estimation

Application of travel demand models followed by traffic assignment gives average speeds and flows on each link for the specified time periods. These were used to compute VMT on each link. The speed vs. emissions *rates* (grams per VMT) relationships for various pollutants and particulate matter were obtained using MOBILE6. Aggregation over all links and time periods gave the total daily emission estimates for drive alone and shared ride trips.

Another tool that can be adopted is TransCAD's emission estimation module which also uses MOBILE6. It divides the whole network into a grid (see Figure F.1) with user specified cell sizes (e.g., Figure F.1 shows 5 mile x 5 mile cells). TransCAD computes the VMT and the average speed in each grid cell based on link locations. However, TransCAD's emissions estimation module does not provide estimates of particulate matter, so it was not used here.

MOBILE6 takes as inputs a wide range of parameters that include vehicle and fuel characteristics. The following section mentions all the possible inputs that a user can specify.

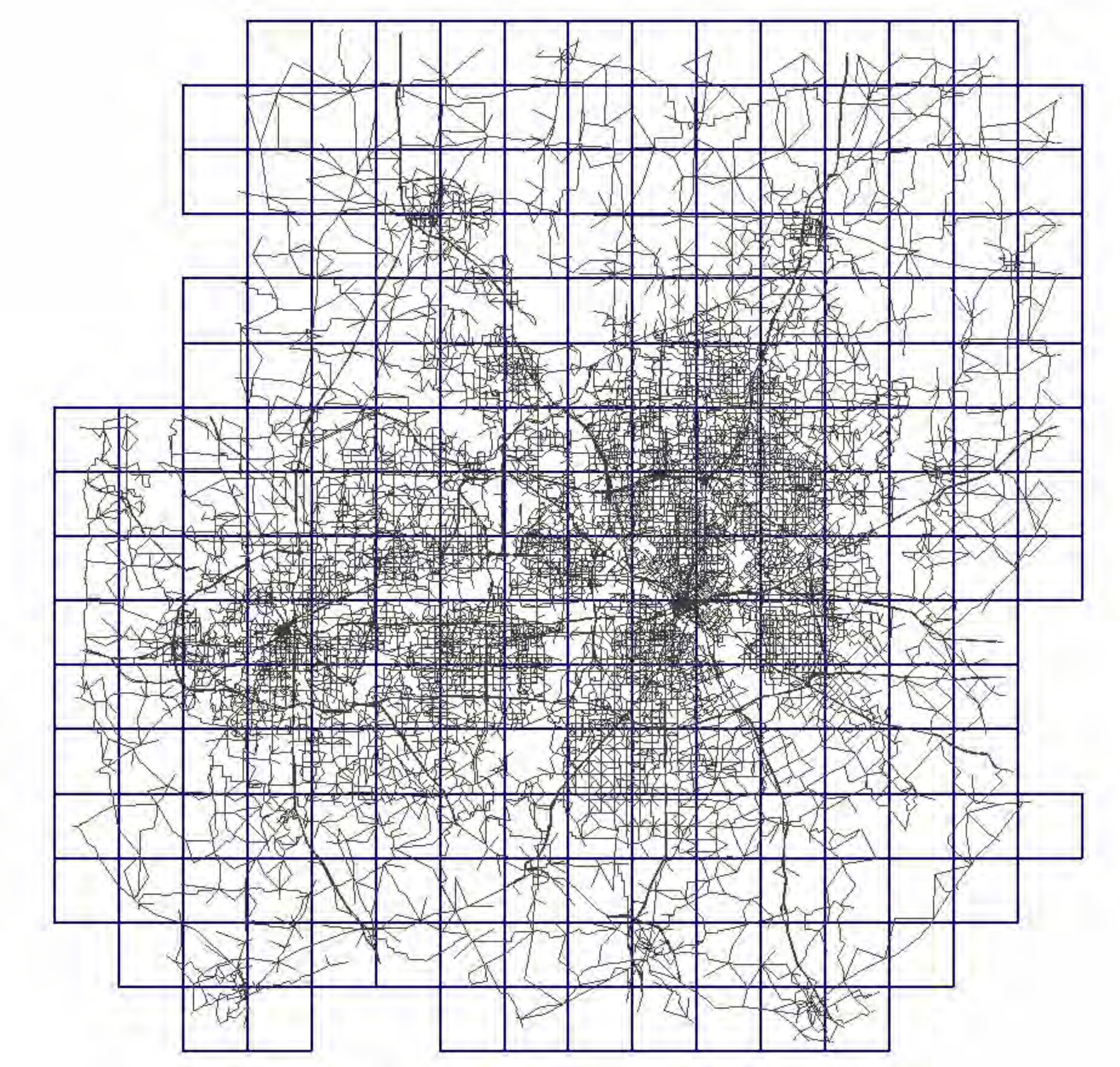

Figure F.1: The DFW roadway network divided into 5-mile grid cells

MOBILE6 Inputs

MOBILE6 can take the following inputs (EPA 2003):

1. Calendar year
2. Month (January, July)
3. Hourly Temperature
4. Altitude (high, low)
5. Weekend/weekday
6. Fuel characteristics (Reid vapor pressure (RVP), sulfur content, oxygenate content, etc.)
7. Humidity and solar load
8. Registration (age) distribution by vehicle class
9. Annual mileage accumulation by vehicle class
10. Diesel sales fractions by vehicle class and model year
11. Average speed distribution by hour and roadway

12. Distribution of vehicle miles traveled by roadway type
13. Engine starts per day by vehicle class and distribution by hour
14. Engine start soak time distribution by hour
15. Trip end distribution by hour
16. Average trip length distribution
17. Hot soak duration
18. Distribution of vehicle miles traveled by vehicle class
19. Full, partial, and multiple diurnal distribution by hour
20. Inspection and maintenance program description
21. Anti-tampering inspection program description
22. Stage II refueling emissions inspection program description
23. Natural gas vehicle fractions
24. HC species output
25. Particle size cutoff
26. Emission factors for particulate matter and hazardous air pollutants
27. Output format specifications and selections

MOBILE6 has default values for all the above variables. However, the user has to, at a minimum, specify the calendar year, maximum/minimum temperature, and fuel volatility.
Depending on the input values, MOBILE6 makes adjustments to the basic emission estimates obtained under typical test conditions. The specified values in the current study are discussed in the following section.

Specified Inputs

Emissions estimates were computed for conditions corresponding to July 2005. The maximum and minimum temperatures specified were 96 F and 77 F respectively, which are the average maximum and minimum temperatures for the DFW region (Weather1, 2005). DFW household survey data suggests that some drivers used vehicles more than 25 years old. Based on this information a vehicle age distribution of 0 to 24 years, the maximum possible range in MOBILE6, was used. MOBILE6's default vehicle age distribution was adopted.

RVP quantifies gasoline volatility, which affects mobile emissions. MOBILE6 takes values between 6.5 and 15.2 and a RVP of 6.8 psi was used for the DFW region (Perkinson et. al., 2004). The analysis used two vehicle classes, light duty gasoline vehicles (LDGVs) and light duty diesel vehicles (LDDVs), among the 28 vehicle classes available in MOBILE6. Both these vehicle classes represent passenger vehicles. MOBILE6's default times of day for peak sun, 10:00 am to 4:00 pm, was used. No cloud cover was assumed. The average sunrise and sunset hours for the month of July in DFW are around 6:30 am and 8:30 pm respectively (Weather2, 2005). The study uses default values of 6:00 am for sunrise and 9:00 pm for sunset since Mobile 6 takes only integer values for this field. The analysis used MOBILE6's default values for all other fields. Based on these values MOBILE6 generated emissions estimates as a function of vehicle speed. The following section mentions various mobile emissions that were estimated in the study and also gives the corresponding emission rates.

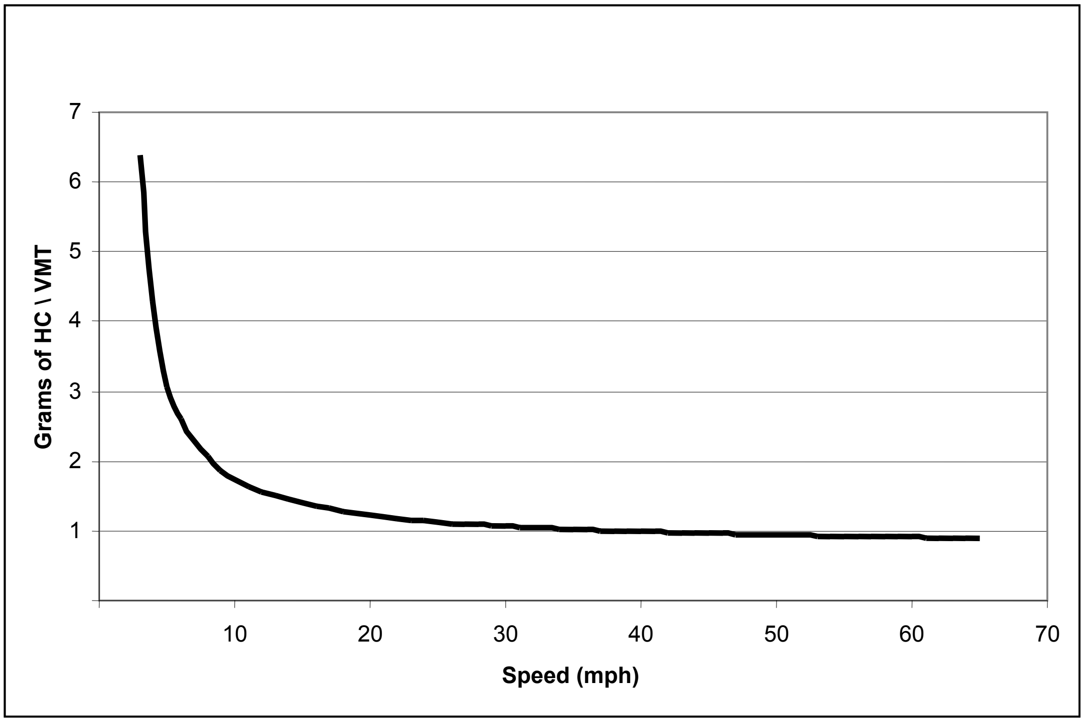

Figure F.2: Hydrocarbon (HC) emission rates at different speeds, according to MOBILE6 defaults

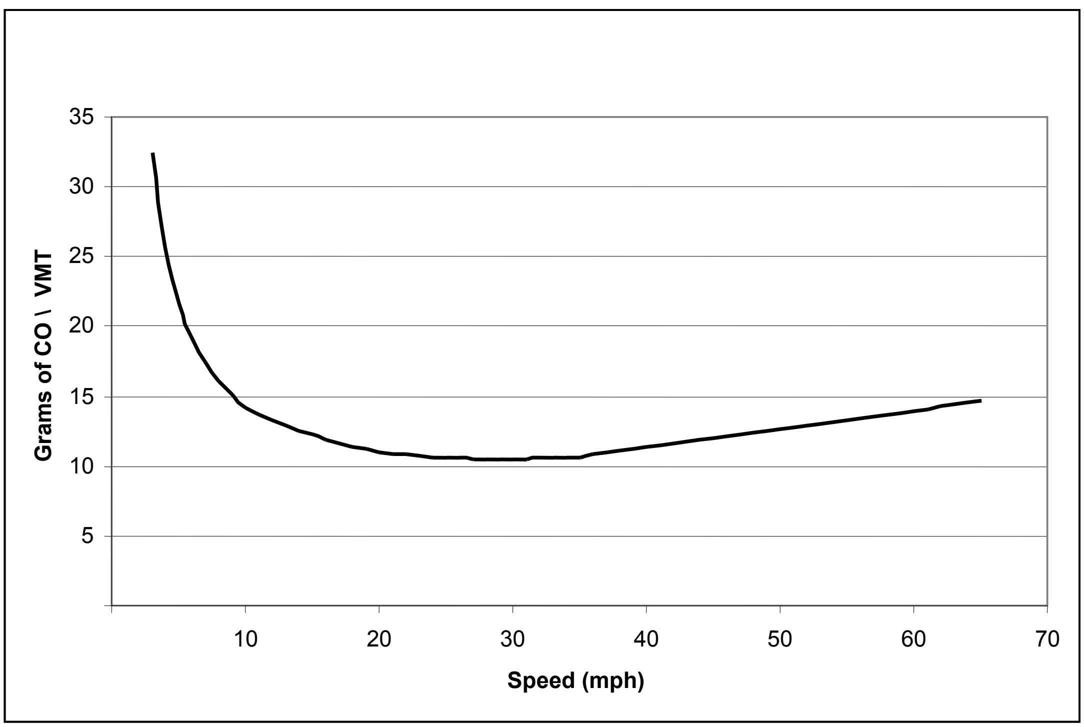

Figure F.3: Carbon monoxide (CO) emission rates at different speeds, according to MOBILE6 defaults

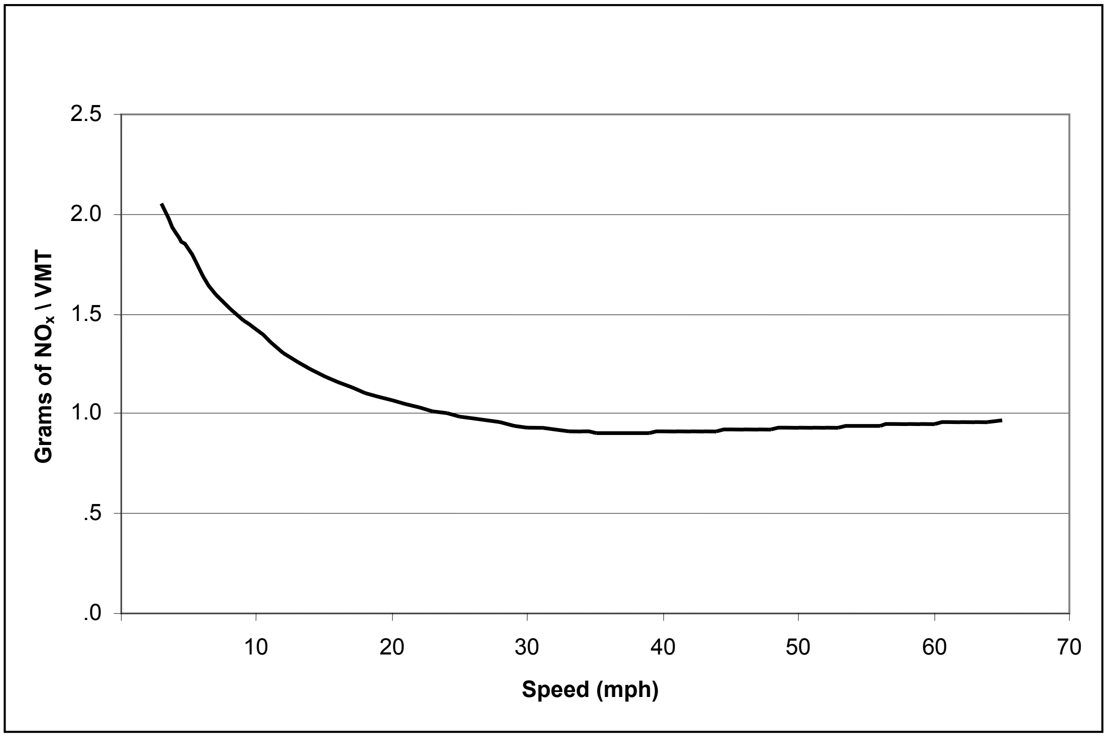

Figure F.4: Emission rates for oxides of nitrogen (NO_x) at different speeds, according to MOBILE6 defaults

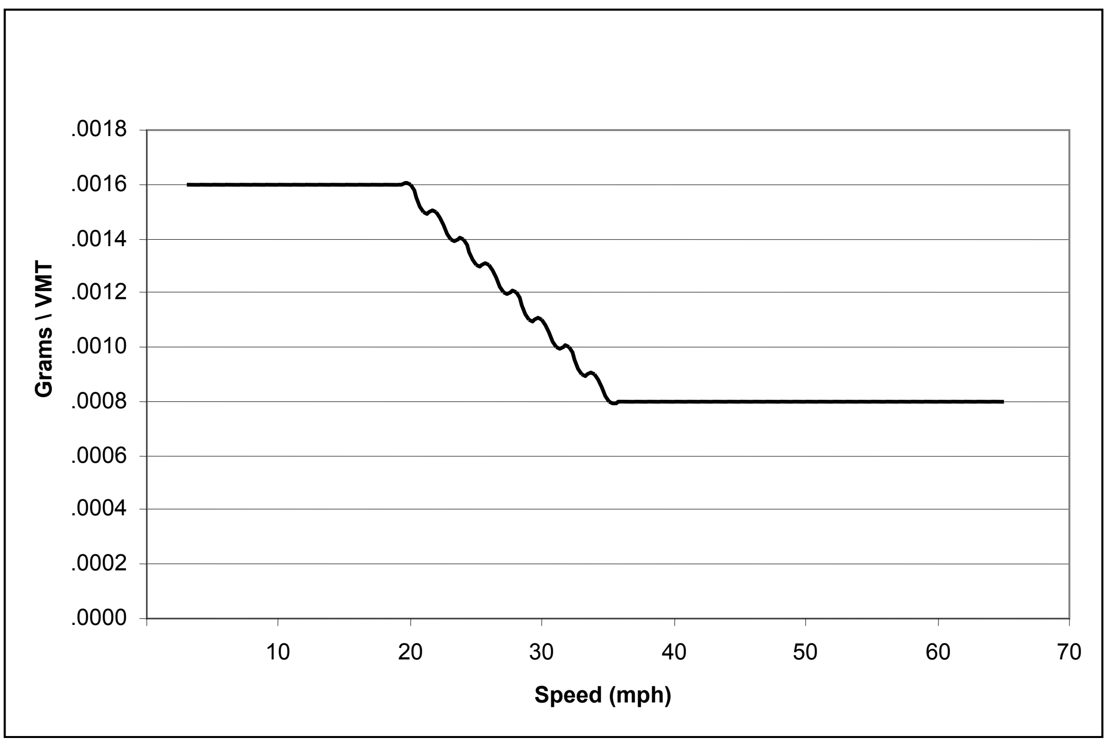

Figure F.5: Emission rates for sulfate portion of exhaust particulate at different speeds, according to MOBILE6 defaults

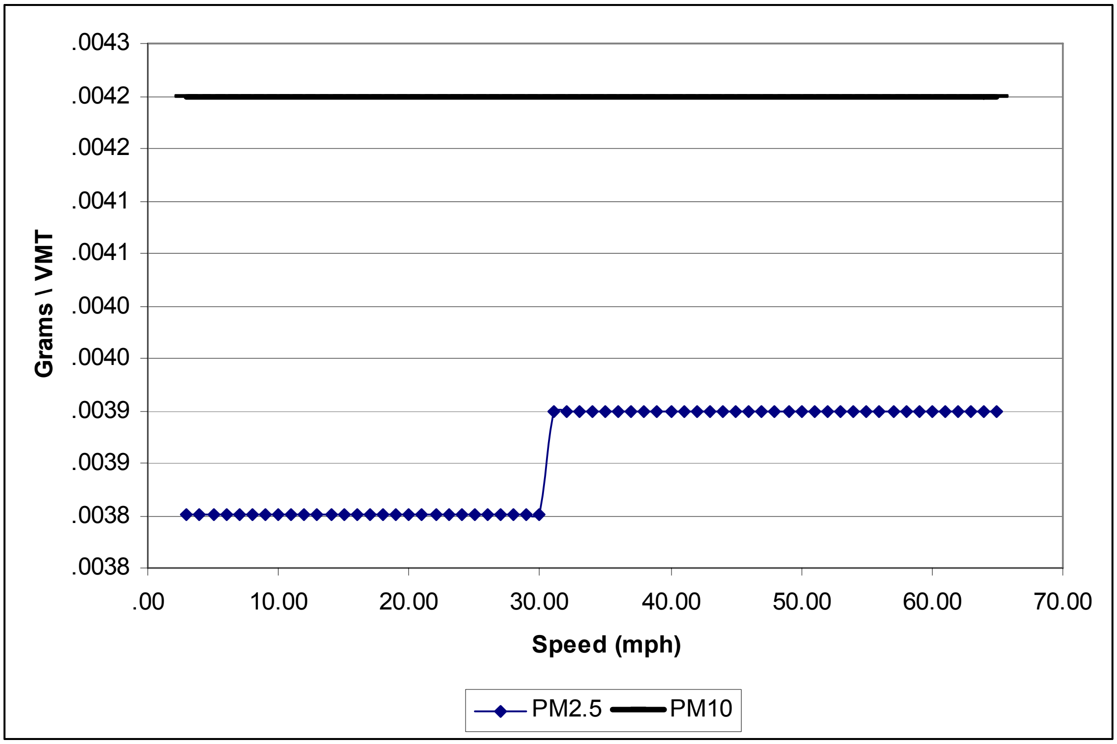

Figure F.6: Emission rates for total carbon of gasoline exhaust particulate at different speeds, according to MOBILE6 defaults

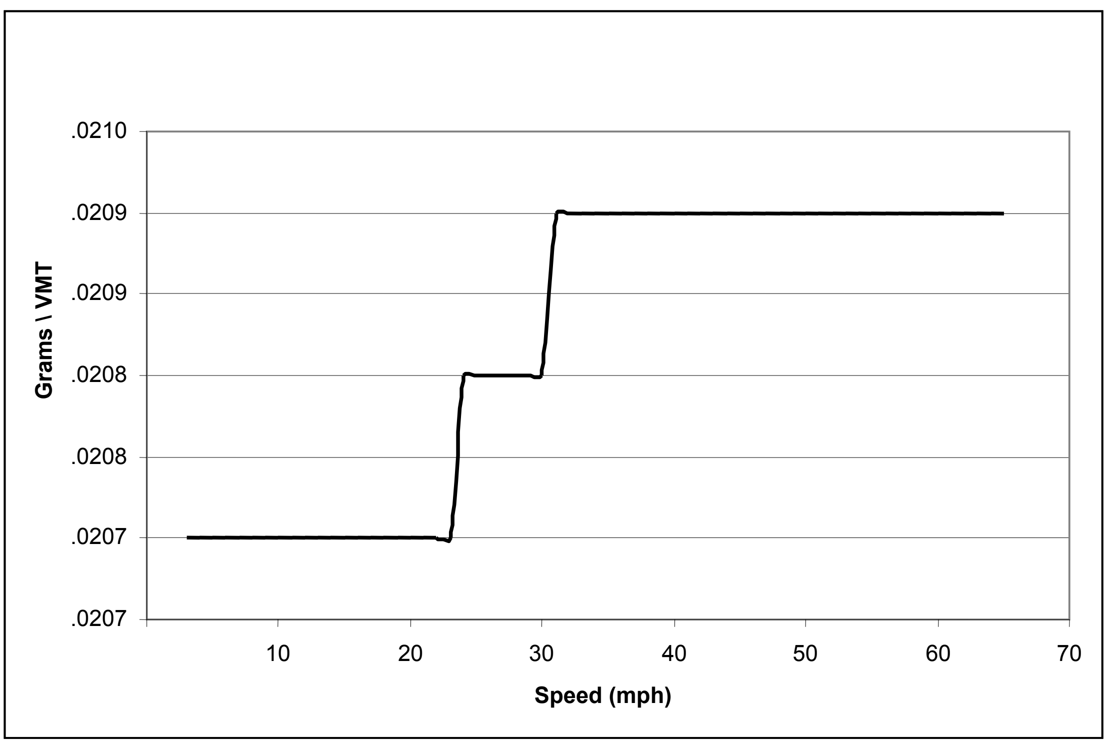

Figure F.7: Emission rates for sulfur dioxide (gaseous) at different speeds, according to MOBILE6 defaults

Table F.1: Emission rates (grams per VMT)

	PM2.5	PM10
Ammonia (gaseous)	0.1016	0.1016
Break wear particulate	0.0053	0.0125
Tire wear particulate	0.0020	0.0080

Limitations

The limitations of the joint DM choice model estimation procedure and the TDM application procedure prove to be limitations for emissions estimation also, since this procedure takes the TDM application results as inputs. Moreover, emissions estimates provided here correspond only to DA and SR trips. Emissions from trucks, buses, and DART trains were not considered, since those behaviors were not explicitly modeled in network assignment of vehicles (except for trucks). One may expect a decrease in truck emissions under MCP, thanks to shorter trip-making[22]. However, transit emissions can be expected to increase only marginally, since DART runs clean buses and the trains are electrified causing little or no emissions. The analysis provides only total daily estimates and not their spatial and/or temporal distribution, as given by TransCAD's emissions module. MOBILE6's default inputs were used for many variables, including for example, vehicle age distribution and share of gasoline-run vehicles to diesel vehicles. These could differ for the DFW situation. One of MOBILE6's limitations is that it does not compute emission estimates for speeds below 2.5 mph and speeds greater than 65 mph since it is unable to give accurate estimates. All three scenarios are predicted to exhibit a significant portion of total VMT at speeds greater than 65 mph (about 29 percent for status quo and 36 percent for MCP scenarios). Estimates for speeds greater than 65 mph were assumed to be the same as estimates at 65 mph, which may not be true. This is evident from the non-zero gradients for emissions rates (at 65 mph) for HC, NO_x, and especially CO (Figures F.2, F.3, and F.4). However, since emission rates appear not to vary much in the 60 mph-70 mph range, so estimates may vary only marginally at higher speeds.

[22] Delivery truck VMT could increase if shoppers turn more to mail purchases, in the face of road pricing. This also would have the effect of reducing total household trip productions, and thus personal VMT. So emissions changes could be more than offset.

Appendix G: CBCP Revenues and Budgets

MCP Tolls

Average MCP tolls on the priced facilities faced by DFW roadway users were computed. Average toll per person trip was computed as the total toll revenues collected during the time period of interest divided by the number of person trips during that period. Average toll rates (per mile) on each type of priced roadway was computed as the sum of tolls on all relevant links divided by the total length of the link lane-miles (by facility type). The daily average toll per person trip was just 4.6 cents for the MCP-on-freeways case and 6.9 cents for the MCP-on-all-roads case. Table G.1 gives the average toll per mile (on freeways) and average toll per person trip during different time periods for the MCP-on-freeways scenario. Table G.2 gives the above values for different time periods and facilities for the 'MCP-on-all-roads' scenario.

Table G.1: Average tolls for the MCP-on-freeways in the long run

Time period	Toll/mile (¢)	Toll/Person-trip (¢)
T0	0.006	0.038
T1	2.619	7.905
T2	0.410	1.556
T3	3.308	8.449
T4	0.523	1.628

Table G.2: Average tolls for the MCP-on-all-roads in the long run

Time period / Facility	Toll / Mile (¢)				
	T0	T1	T2	T3	T4
Freeways	0.006	2.787	0.424	3.171	0.552
Principal Arterials	0.005	4.100	0.404	5.066	0.598
Minor Arterials	0.000	1.294	0.050	1.541	0.080
Collectors	0.000	0.994	0.051	1.072	0.075
Ramps	0.011	1.486	0.412	1.620	0.488
Frontage	0.000	0.612	0.070	0.688	0.087
HOV	0.000	2.224	0.316	3.750	0.491
Total network	0.002	1.655	0.166	1.925	0.228
Toll/person-trip (cents)	0.058	12.707	2.234	12.172	2.432

Tolls for MCP-on-freeways scenario

The following analysis gives a sense of the cost an average DFW commuter would face where freeways are priced. From the DFW household survey data, the average one-way commute distance is 12.6 miles with a standard deviation of 10.1 miles. A typical commute trip involves traveling to work in the AM peak-period and traveling back home in the PM peak-period. The VMT distribution by roadway facility for the MCP-on-freeways scenario indicates that 52.4

percent of the VMT in the AM peak-period and 51.3 percent of the VMT in the PM peak-period occurs on freeways. However, the peak-periods also involve non-work trips. The work trips can be expected to have a higher percentage of VMT on the freeways than the non-work trips. So, the average commuter is assumed to travel 70 percent of the trip distance by freeways. An average commuter commuting the mean distance of 12.6 miles one way (58th percentile distance in the survey) would travel 8.8 miles on freeways. He/she would have to pay a daily toll of about 50 cents (8.8(2.619+3.308) = 52.1 ¢). A person commuting a 23 miles one way (the 85th percentile distance), would travel about 16 miles on freeways. He/she would have to pay a daily toll of about $1.00 (16(2.619+3.308) = $0.94.8). A person commuting 33 miles one way (95th percentile distance) would travel about 23 miles on freeways. He/she would have to pay a daily toll of about $1.50 (23(2.619+3.308) = 138.4 ¢).

The *average* toll-per-mile value might be far off from the actual toll rate on some congested roads. So, to get a better idea, the tolls for commuting to the Dallas CBD from specific locations in the metropolitan were computed. Table G.3 gives CBCP toll estimates for someone commuting to work and back home during peak-periods.

Table G.3: Approximate tolls for a round trip commute to Dallas CBD from various regions (MCP-on-freeways)

From	Work trip toll ($) /day		Round trip distance (miles)
	Long-term	Short-term	
Plano	3.00	4.00	45
Fort Worth	3.50	7.00	68
Carrollton	2.00	4.00	53
Arlington	2.00	4.00	40
Mesquite	1.00	2.50	26

Typical routes were assumed for the above commute trips. The approximate start and end locations for the various trips are given in Figures G.1 through G.5. These correspond to trips from Plano, Fort Worth, Lewisville, Arlington, and Mesquite, respectively. Bold links on the network in the above mentioned figures indicate freeways (which are priced in both MCP scenarios).

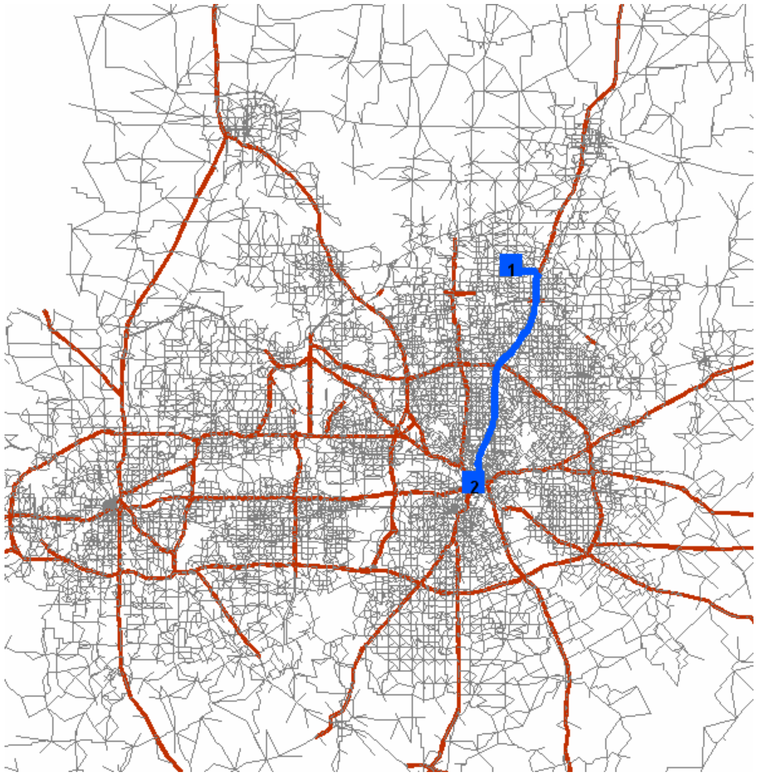

Figure G.1: Route to and from Plano to Dallas CBD

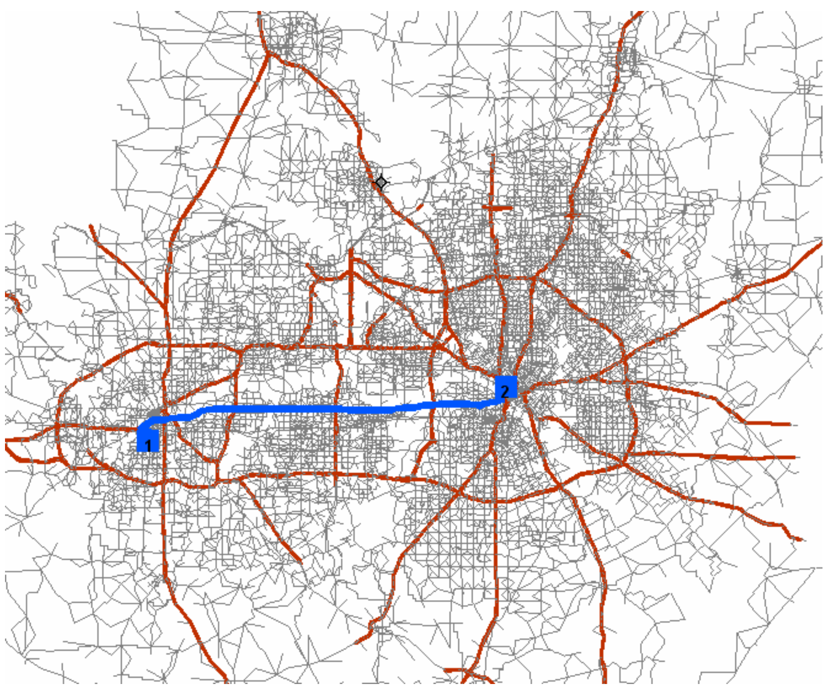

Figure G.2: Route to and from Fort Worth to Dallas CBD

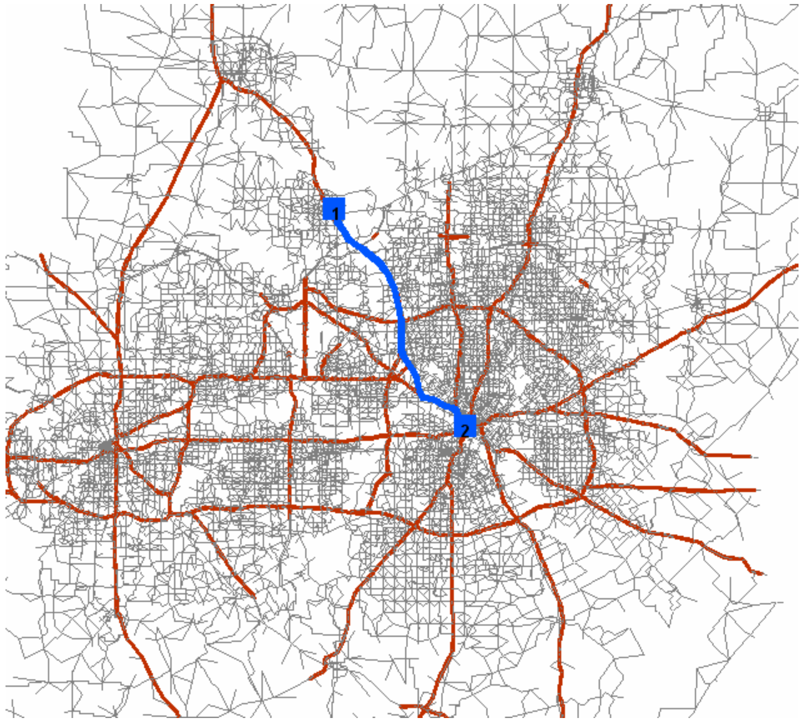

Figure G.3: Route to and from Carrollton to Dallas CBD

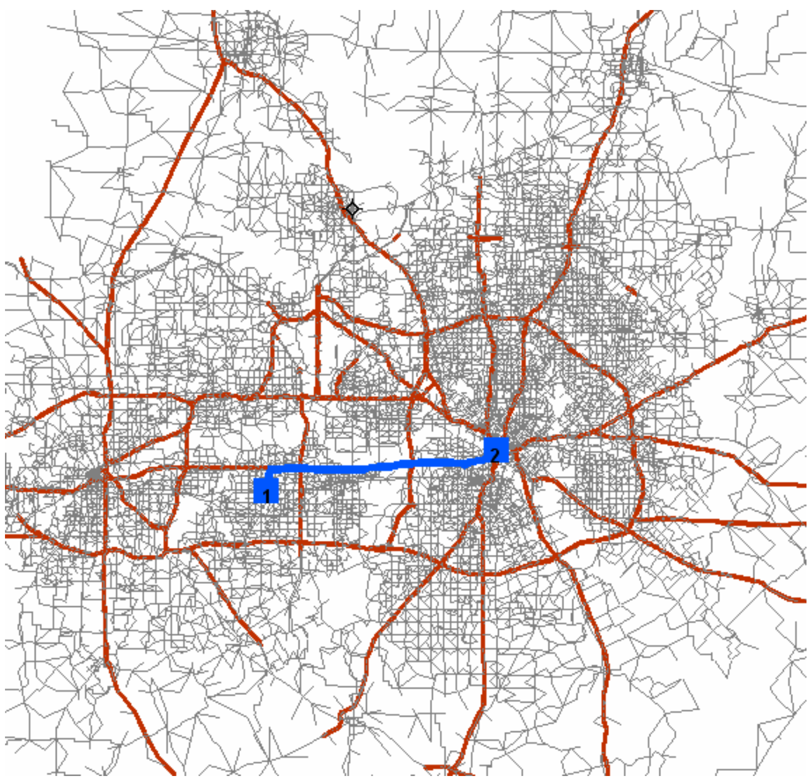

Figure G.4: Route to and from Arlington to Dallas CBD

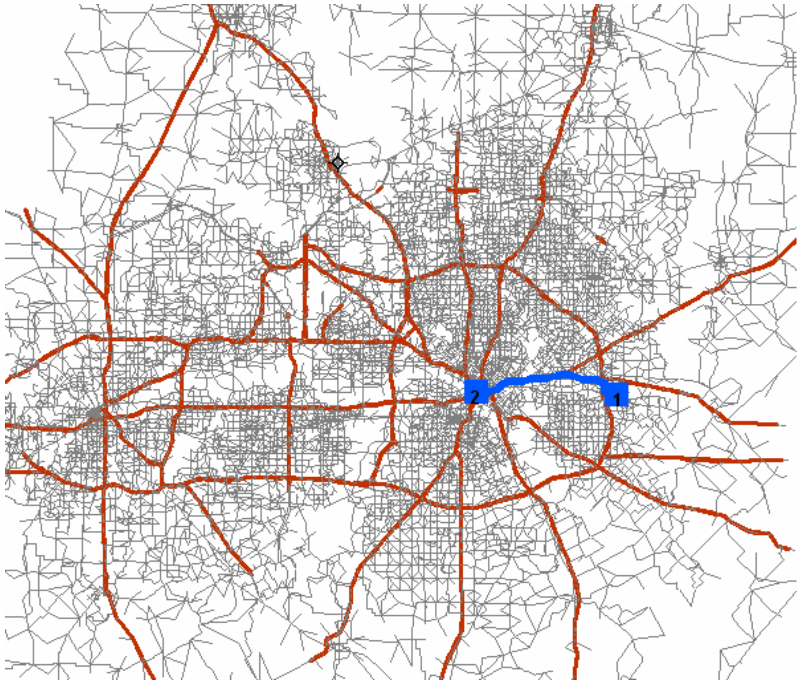

Figure G.5: Route to and from Mesquite to Dallas CBD

Cost Estimates

Estimates of initial investment and recurring costs are required to predict net revenues and potential travel budgets for those who qualify. This section computes the initial investment costs for roadside devices and other technology based on USDoT (2000a and 2000b) values. The North Texas Tollway Authority's (NTTA) administrative expenditures for the financial year 2003 were used to estimate operations and management (O&M) costs for a DFW CBCP application. To assume that all freeways would be priced is conservative, since not all freeways are congested. DFW has 594 centerline miles (USDoT, 2000c) (about 3700 lane miles) of freeways. TDM results for the status quo suggest that about 60 percent of which are "congested" (V/C > 0.75). The following analysis assumes that 70 percent of the DFW freeway network is priced, i.e. about 415 centerline miles and 2600 lane-miles.

Initial Costs

Two USDoT reports (USDoT 2000a and 2000b) give a range of costs for toll plaza and toll administration equipment. These were used here to estimate total initial costs. Assuming one toll plaza every 3 centerline miles (as suggested by toll technology experts) requires around 140 toll plazas. Since only one gantry structure is assumed for all the lanes at any point, the higher USDoT estimate is used for mainline structure (see Table G.4). Since there are multiple lanes at each plaza, 700 electronic toll readers are required. This is assuming one reader per lane for the 5 lanes on average, which is more than the actual average value of about 4.2 lanes (both directions) – and thus is felt to be conservative. Around 350 high-speed cameras (each costing $7,500) would be required (one for every two lanes, to permit violation detection and facilitate policy enforcement [USDoTa, 2000]).

Table G.4: Initial technology cost estimates for a CBCP application on DFW freeways

(All cost estimates are in 2003 US dollars.)

One-time investment	Unit cost estimate	No. of Units	Total Cost
ETC structure	$15,000	140	$12,100,000
ETC software	7,500	140	1,050,000
ETC readers	3,500	700	2,450,000
High speed cameras	7,500	350	2,625,000
Toll administration hardware (Includes 2 workstations, a printer, and modem)	12,500	1	12,500
Toll administration software (Includes COTS software and database)	60,000	1	60,000
Toll tags*	10	3,000,000**	30,000,000
Total cost			$48,297,500

* eGo™ 2201 (Transcore, 2002)

** This is the number of vehicles in DFW. The number of households in the year 1999 is 1,808,402. 35 percent have 1 vehicle, 41.6 percent have 2 vehicles, 12.8 percent have 3 vehicles, 3.3 percent have 4 vehicles, 1 percent have 5 or more vehicles (1990 US census). This gives about 3 million vehicles.

The initial cost is estimated to be $48.3 million (Table G.4), which amounts to about $11.00 per DFW resident. Readers should note that transponders (represent 62 percent of the total costs) could very well be covered by user deposits/purchases. Moreover, toll technology already exists in several localities and flat-rate tolling may be needed in several corridors regardless.

Recurring Costs

Operating expenses for the NTTA (NTTA, 2003), New Jersey Turnpike Authority (NJTA, 2003), and San Joaquin Hills Transportation Corridor Agency (SJHTCA, 2003) were used to arrive at system costs of a DFW ETC application. Table G.5 shows expenses as computed per lane mile. Depreciation and amortization expenses were excluded since they result from financing decisions. Manual toll collection costs and NJTA state police, snow removal, and toll-tag pre-payment expenses also are not included, since they are not recurring costs for a DFW CBCP application.

Table G.5: Recurring (annual) cost estimates for various ETC projects.

Toll Road Program	Operating Expenses	Lane-miles of Toll Roads	Expenses per Lane-Mile
NTTA	$32,553,600	313	$104,005
NJ Turnpike Authority	$140,023,307	1,219	$114,867
San Joaquin Hills	$9,530,000	108	$88,241

Since a CBCP application is very similar to a standard ETC application, expanding ETC operating costs per lane mile is justified. One major distinction arises from maintaining CBCP travel budget accounts. Maintaining such accounts involves creating and verifying budgets and additional, secure record keeping. Thus, it involves personnel from the Legal, Audit, Accounting and Community Affairs departments; so the corresponding NTTA expenses were doubled, resulting in a cost "cushion" of 9.1 percent over a regular ETC facility.

CBCP operating expenses per lane-mile are estimated at $100,000 per year, or a total of $260 million for the DFW region's freeway system annually. This corresponds to $54.00 per DFW resident. In comparison, DFW residents are estimated to experience an average annual congestion cost of $564.00 (per resident), which includes delay and fuel costs on all congested roadways (Schrank and Lomax, 2003). About 78 percent of the congested (V/C > 0.75) VMT takes place on the freeways, so 78 percent of the congested costs could be attributed to freeways. This is equal to $440.00 per DFW resident. The total cost per resident obtained by applying a capital recovery factor to the initial cost (at an interest rate of 6 percent over a period of 10 years, the lifetime of the ETC system) is about $55.00. $55.00 per year per resident seems like a reasonable investment in order to address freeway congestion. These cost calculations appear to support the case for CBCP as a worthwhile congestion mitigation strategy in a region like DFW. Based on the predicted net revenue from MCP tolls, the following section computes travel budgets for a CBCP application in DFW.

Budgets

Traveler CBCP budgets can be estimated based on a comparison of MCP revenues with system implementation costs (both operating and capital costs). The total daily toll revenues collected for both MCP scenarios was computed based on toll rates and link VMTs. As an example, MCP-on-freeways resulted in about $2.4 million in daily toll revenues in the short run (fixed employment locations), and $1.6 million in the longer run. Daily revenues of $2.4 million suggest monthly revenue of about $52.8 million (considering revenue from 22 weekdays only, and thus ignoring any weekend revenues [when traffic congestion is often lighter]).

Annual operating expenses of $260 million suggest monthly operating expenses of $21.7 million. The monthly cost obtained by applying a capital recovery factor to the initial cost (at an interest rate of 6 percent over a period of 10 years, the lifetime of the ETC system) is about $0.55 million. So, the *net* monthly revenue from MCP-on-freeways is estimated to be $30.6 million (when work destinations are held fixed, or about $13 million when destinations are made flexible). The total number of vehicles in DFW region is estimated to be around 3 million (see discussion under Table G.4). Each household owns 1.9 vehicles on average. Since a person with more than one vehicle registered under their name may be offered a single budget only, the number of budgets may well be less than the number of vehicles in the DFW region. If one assumes that 30 percent of the households have the same owner for all of the household's vehicles, then there would be 2.1 million people eligible for a budget, if there are no additional budget eligibility criteria. This could be a conservative estimate. However, the operating costs are also conservative estimates and could be expected to be significantly lower since the application is on a large scale, unlike the case studies considered. If the budget were to be allocated uniformly among all the above individuals, each would get a monthly budget of $14.60 under this scenario (MCP-on-freeways, in the short-term).

However, CBCP could be designed so that only freeway-using commuters receive travel budgets. There are 3.97 million home-based work trips in the DFW region and about 3 million jobs (when summing the number of basic, service, and retail jobs in the NCTCOG database on attractions), so 3 million commuters may be expected. Not all use freeways, however, so perhaps only 90 percent of these commuters may be considered eligible for a travel budget. In this case, eligible travelers would receive a monthly budget of $11.30.

The same analysis as above was conducted for the MCP-on-Freeways scenario in the long run (employment locations flexible). Revenue computations indicate daily revenues of $1.6 million. Further analysis suggests monthly budgets of about $6.00 per eligible user, if budget were to be allocated uniformly among 70 percent of the vehicle population, or about $5.00 per month, if only freeway commuters were considered.

Appendix H1: Review of Congestion Pricing Technologies

Congestion pricing as a concept has been in vogue for some time (e.g., Vickery 1959). However, technologies to implement the theory were not developed until the 1970s, and they have been evolving since then. There are numerous electronic road pricing (ERP) technologies now available, each with different capabilities and system architectures for distinct pricing applications. Given the variety and complexity of available technology, there is a need to synthesize all this information for organizations such as the Texas Department of Transportation (TxDOT) who wishes to select a particular pricing technology. The literature provides substantial information related to ERP technologies (see, e.g., Pietrzyk and Mierzejewski (1993), Spasovic et al. (1995), Porter et al. (2004)). This section reviews and summarizes both existing and conceptual electronic toll collection (ETC) technologies and identifies system capabilities and functional requirements. On the basis of this information, TxDOT officials wishing to implement standard ETC technologies can examine their requirements and select the appropriate technology. In addition, this review is intended to be useful in subsequent sections for evaluating credit-based congestion pricing (CBCP) technologies. This section is composed of five subsections:

- automatic vehicle identification (AVI) technology,
- basic structure of an ETC,
- performance testing of ETC systems,
- ETC system design issues
- institutional and implementation issues

Automatic Vehicle Identification Technology

AVI technology is used to collect real-time traffic information and monitor traffic conditions. Pietrzyk and Mierzejewski (1993) described the interrelationship among AVI, ETC, and electronic toll and traffic management (ETTM) as follows. AVI involves wireless communication between transponder-equipped vehicles and roadside, overhead, or in-pavement sensors. An ETC system uses AVI technology for efficient and secure collection of tolls without manual involvement; whereas ETTM uses AVI technology for other traffic management purposes—for example, to get real-time travel time information.

In general, the operation of AVI technology is composed of three tasks (Pietrzyk and Mierzejewski, 1993):

- intercepting modulated electromagnetic radiation from a vehicle,
- recovering the information contained in the signal, and
- using a computer to identify the tag from a database.

AVI technologies are differentiated by the way in which these tasks are accomplished. There are three types of AVI transponders (Koelle, 1992).

- Type I transponders can only be read or be interrogated to reflect unique vehicle identification data,
- Type II transponders can be read from and written to in order to store and update unique variable data such as entry/exit locations, account balance, vehicle maintenance/inspection reports, and so forth.

- Type III transponders have the capability to interact and communicate with the driver.

Existing AVI technologies can be categorized into six systems with respect to the frequency of the electromagnetic radiation, signal modulation (i.e., tuning or adjustment) method, and whether the tag is active or passive (i.e., radiation-generating tag or radiation-reflecting tag) (Pietrzyk and Mierzejewski, 1993). The AVI station that is in use in Houston is shown in Figure H1.1.

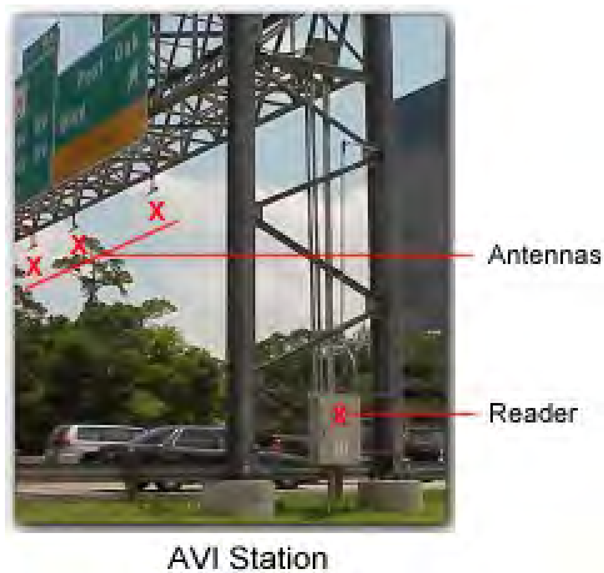

Figure H1.1: An AVI Station Installed in Houston, Texas

(Source: http://traffic.houstontranstar.org/aviinfo/avi-tech.html)

The literature describes six types of AVI technologies:

- inductive loop system,
- optical license plate ID system,
- bar code system,
- active radio frequency (RF)/microwave system,
- passive RF/microwave system, and
- surface acoustical wave (SAW).

Note that there are three frequency ranges currently in use (Pietrzyk and Mierzejewski, 1993):

- very low frequencies (below 200 kHz), used in inductive loop systems;
- microwave frequencies (500 to 3,000 MHz), used in active RF systems, passive RF systems, and SAW systems; and
- optical or near-optical frequencies (30 GHz to 1,000 GHz) including infrared, used in optical license plate ID systems, and bar code systems.

Inductive Loop Systems

The earliest of the AVI technologies, inductive loop systems are the only systems that employ very low frequencies (Pietrzyk and Mierzejewski, 1993). A tag is mounted on the underside of the vehicle, and a loop antenna is embedded beneath the surface of the roadway. The roadway antenna sends out an interrogation signal, and the tag replies by returning a signal including data stored in the tag. This system normally is an active system because the tag transmits its own signal. If the system is a passive system, the tag simply reflects the interrogation signal (Pietrzyk and Mierzejewski, 1993).

Optical License Plate ID Systems

Optical license plate ID systems employ optical or near-optical frequencies (Pietrzyk and Mierzejewski, 1993). The system reads license plates directly and identifies the vehicle from a database. A video camera captures an image as the vehicle passes the toll plaza; then the image is digitized and processed to pull out the license plate number. Because the image processing can typically take nearly one second, which is considered to be relatively lengthy, multiple reads for improving reliability are impossible (Pietrzyk and Mierzejewski, 1993), which is a limitation of this method.

Bar Code Systems

Bar code systems, like the optical license plate ID systems, employ optical or near-optical frequencies (Pietrzyk and Mierzejewski, 1993). The vehicle tag is simply a bar code, which is scanned by a constant laser. The reflected signal is processed to pull out the code. This image processing is much simpler than the optical license plate ID systems, because the reflected laser signal represents a one-dimensional image whereas the video image of the license plate must be processed in two dimensions (Pietrzyk and Mierzejewski, 1993).

Active Radio Frequency/Microwave Systems

Active RF systems employ microwave frequencies (Pietrzyk and Mierzejewski, 1993). Owing to its high data rates, the system incorporates multiple transmissions to improve reliability. These transmissions are commonly known as "handshakes" in the industry. The systems use active tags that require a power source such as a battery or a connection to vehicle power. In the active RF/microwave system, a transmitter sends out a very short interrogation signal, triggering the circuitry in the vehicle tag, which in turn responds by generating a microwave signal containing the data stored in the tag. This signal is transmitted to a receiver that decodes the data and sends them to a computer for identification (Pietrzyk and Mierzejewski, 1993).

It is important to note that the RFID technology discussed here in sections 2 through 5 is the standard RFID technology. It should be distinguished from the next generation of low-cost "smart" RFID systems that are currently being developed at the Auto-ID Center (Sarma, 2003; Juels et al., 2003). This "smart" RFID technology is proposed in Section 6 as a potential technology for CP based on other related applications (e.g. ActiveWare's RFID fleet maintenance, as described at http://www.activewaveinc.com/applications_fleet_maintenance.html).

Passive Radio Frequency/Microwave Systems

Passive RF systems, also known as the “backscatter” method (Pietrzyk and Mierzejewski, 1993), employ microwave frequencies and passive tags that simply reflect the received microwave signal. The passive tags may or may not require a power source. In these systems, the transmitter usually transmits a signal continuously, and the vehicle tag intercepts this signal and reflects the modulated signal to a receiver. The amount of reflection varies according to the data stored in the tag. The received signal is decoded to recover the data, which are sent to a computer for identification (Pietrzyk and Mierzejewski, 1993).

Surface Acoustical Wave Systems

SAW systems also employ microwave frequencies (Pietrzyk and Mierzejewski, 1993). The major difference between SAW and RF microwave systems is that the SAW transponder is non-programmable. In these systems, the AVI reader sends out a low-powered RF signal, and the transponder antenna captures this signal. A lithium crystal is then energized, and an acoustic wave is set up along its surface. This acoustic wave travels along the surface of the crystal so that etched metal taps can be used to send back a series of time-delayed reflections of the original signal for identification (Pietrzyk and Mierzejewski, 1993).

The pros and cons of the six systems are summarized in Table H1.1.

Table H1.1: Advantage/Disadvantages of Six AVI Systems (Pietrzyk and Mierzejewski, 1993)

AVI Systems	Pros	Cons
Inductive Loop Systems	• very low potential for electrical interference • lower potential for interference from adjacent lanes due to short coupling range • simple serviceability • increased reliability due to proximity of loop antenna and tag • ATM/ATIS can benefit the inductive loop systems, and the infrastructure is already in place for more IVHS related applications	• lower max data rate resulting from the use low frequency; however, it is fast enough for multiple transmissions to increase reliability • medium difficulty in duplicating tags • usually active tags are used that require a power source • tag installation is less convenient than that of a windshield-mounted tag • more sensitive to environmental conditions
Optical License Plate ID	• no need for vehicle tag • license plates are far less likely to be duplicated • no chance of interference between adjacent lanes	• processing algorithms are computationally expensive • owing to the relatively long time required for image processing, multiple reads to improve reliability are impossible • very low reliability (80–90 percent) • many conditions cause system failure: dirty or damaged license plates, bumper stickers and similar text on a vehicle, and reduction of visibility caused by rain and fog • Typically requires fully reflectorized license plate
Bar Code	• more reliable and much faster than optical license plate ID systems because of the single dimension • very simple vehicle tag: a bar code imprinted on an adhesive strip • low potential for interference between adjacent lanes because of limited range	• easier to duplicate tags than other systems • rain, fog, dirt, or moisture on tag cause failure • high restrictions on the position and speed of the vehicle as it passes the reader • less reliable than microwave systems because of computationally intensive image processing
Active RF/Microwave Systems	• more reliable and less chance of electrical interference than a passive system because of the stronger return signal • greater operating range than a passive system because of the use of active tags	• active tags are not powered by interrogating beam, so they must have a power source • higher probability of lane-to-lane interference due to stronger return signal • higher manufacturing costs resulting from more complexity in the tag circuitry
Passive RF/Microwave Systems	• passive tags do not need a power source • tags are less complex than those in an active system	• less reliable than an active system • higher susceptibility to electrical interference due to weaker return signal • shorter operating range because the tag is powered by the interrogating beam
SAW Systems	• virtually impossible to duplicate the vehicle tag • lower manufacturing costs resulting from much simpler tag circuitry • tags do not need a power source	• a limited operating range (up to 15 ft), because it is typically part of a passive system • limited data transmission rate, because microwave energy must be converted into mechanical energy • non-programmable tags

Basic Structure of an Electronic Toll Collection System

An ETC can be defined as a programmable remote AVI system that uses microwave technology to identify the presence of a vehicle in the traffic stream and to automatically calculate and charge the vehicle's driver for the use of the tolled road (Hensher, 1991). ETC systems have gained practical importance over the last fifteen years because of the inherent inefficiencies involved in traditional manual toll plazas. An ETC system is composed of three parts:

- a vehicle with an on-board unit (a transponder),
- a two-way microwave link, and
- roadside or tollgate equipment.

A transponder can be a tag, an integrated circuit (IC) card with a card holder, or a combination of the two. It stores the information needed for toll transactions, such as vehicle type, account identification, balance, and so forth. The roadside equipment consists of three parts:

- a transceiver (transmitter and receiver) or reader and decoder,
- a lane controller, and
- a primary processing computer system.

The transceiver verifies the functionality of the transponder and conducts the transaction. The lane controller monitors activities in a toll lane. The computer system accesses account information and processes the transaction requests. The different components of the ETC system are described below in detail.

Transaction Process

Transaction processes can be divided into two categories according to the ETC system operations (Spasovic et al., 1995): open ETC operation and closed ETC operation. In the open ETC operation, the transceiver debits the vehicle's account and simply sends a receipt to the transponder without writing transaction information on the transponder's memory. In the closed ETC operation, the transaction process is more complex: The transceiver first reads the memory content of the transponder; then the computer verifies the vehicle ID, account number, and whether sufficient funds are available in the account. The transceiver then writes a date, time, location, and lane number stamp in the appropriate fields of the transponder's memory. When the vehicle exits the system, the transceiver reads the transponder's memory and the computer calculates the toll and debits the vehicle's account. This information is then written back to the transponder's memory (Spasovic et al., 1995).

Antenna Types and Location

For RF/microwave AVI systems, there are two antenna types: in-vehicle and roadside (Spasovic et al., 1995). In the in-vehicle equipment, the antenna is combined within the equipment itself and is compact. In the roadside equipment, the antenna is installed at the toll plazas. There are three kinds of roadside antennas, which are classified according to location: in-pavement, distributed overhead, and focused beam. Another type of roadside antenna, called a multiplexing antenna, reads multiple tags over multiple lanes. There are three types of antenna configurations, depending on the manufacturer: The one-antenna type uses only one antenna for both triggering (sending an interrogating signal) and communicating. In the two-antenna type, one antenna is used for triggering and another is used for communicating. In the three-antenna type, one antenna is used for triggering, one for communicating, and one for collecting position information to adjust the RF power output level or adjust antenna propagation patterns to optimize communication. To select the appropriate antenna configuration, the frequency, in-vehicle unit properties, and communication distance should all be considered (Spasovic et al., 1995). The communication distance and the length of the coverage area, where all ETC transactions take place, are usually not greater than 40 m or 137 ft (Saab, 1991). This distance is determined by receiver sensitivity, antenna type, location, and transmitted power.

The variations in the design of in-vehicle equipment are considered major, whereas those of roadside units are not (Spasovic et al., 1995). The in-vehicle equipment is composed of either a tag or an IC card and a card reader. The tag is a small electronic device attached to the windshield of a car. The IC card and card reader are usually installed in the dashboard. Thus, the ETC systems can be divided into two categories: tag-based and IC card-based.

Tag-Based Electronic Toll Collection Systems

The components of these systems include tags, data processing, communication capabilities, and RF devices (Spasovic et al., 1995). The function of the tag is to communicate without physical contact with a specific station over a distance of a few meters. The structure of the tag consists of several functional electronic circuits such as RF modulation, memory, and antenna.

IC Card-Based Electronic Toll Collection Systems

This type of system has IC card-based in-vehicle equipment consisting of an IC card, a card reader, and an RF link unit (Spasovic et al., 1995). The IC card replaces the tag and provides a means for storing information during transactions. The RF link unit can be a tag mounted on the windshield or any other form of transponder that can establish a communication link between an IC card reader and the roadside equipment. One of the advantages of using an IC card is its greater security, because it is possible to encrypt the data in a more sophisticated manner to protect data integrity. Other advantages of the IC card-based systems over the tag-based systems are the IC card's flexibility—that is, it can be modified to new standards relatively quickly and at a relatively low cost—and the ability to replace non-functional memory by redesigning the memory map of the card using an operating system command (Spasovic et al., 1995).

The advantages of using ETC systems are listed as follows.

- ETC provides the possibility of setting virtually any toll-pricing scheme based on distance, time of day, type of vehicle, speed of travel, travel types entitled to discount, and so forth.
- Evidence from Norway (as explained in detail in Section 3) in 1988 shows that an ETC lane can handle three times the volume of traffic of a manual toll plaza.
- The Norwegian experience shows that the cost of installation per lane for a full ETC system is between 33 and 50 percent of the cost of a manual coin collection system (Hensher, 1991).
- Quick payment via stored value cards or encoded AVI tags (like credit cards) is possible and is becoming increasingly popular.
- Studies by Hensher et al. (1989) showed that significant travel time savings could be obtained by using ETC systems rather than manual plazas.

The next subsection describes the tests performed to evaluate various ETC systems to assess their performance and functional reliability.

Performance Testing of Electronic Toll Collection Systems

Performance testing of ETC systems is an important task in evaluating the functional reliability of the system. Different tests have been proposed in the literature, and some of them are reviewed here. Pietrzyk and Mierzejewski (1993) indicated that many of the toll collection agencies that have investigated or implemented ETC systems have conducted some type of performance testing. However, the findings of these evaluations have not been formally documented and published, and in many cases, the results are proprietary. Test plans that were available indicated that these evaluations were not standardized tests and satisfied only specific agency concerns or requirements.

Spasovic et al. (1995) proposed ETC system test protocols that include three types of tests: static or controlled tests, functionality tests, and long-term tests. In a somewhat earlier work, Spasovic et al. (1994) provided detailed descriptions of the test protocols. Table H1.2 offers a brief description and comparison of the tests.

Table H1.2: Summary of Test Protocols (Source: Spasovic et al., 1995)

Tests	Static Tests	Functionality Tests	Long-Term Tests
Testing place	Performed in a laboratory	Performed in a laboratory simultaneously with static tests	Performed in an actual toll collection setting
Test subjects	• communication range and speed • ability to withstand interference • reliability under harsh weather conditions • electronic component reliability	• correctness of transaction information • fraud or cheating tests to identify potential loopholes in the systems	• operational reliability of the system

Different methods to test ETC systems were provided by ETTM (1994). The accuracy of an ETC system is defined in terms of two measures: capture rate and error rate. The capture rate is the percentage of successful readings and decodings of a properly mounted tag's data message. The error rate is the percentage of reading errors of a tag's identification fields. Regardless of the hostility of the operating environment, an ETC system must have a capture rate greater than 99.95 percent and an error rate less than 0.00001 percent. Spasovic et al. (1995) proposed sample size estimation. The binomial distribution is used for the probability of k successful transactions during n tests. The maximum likelihood estimation method is used for estimating the probability of a successful transaction (p). The probability of failure (q) is $1 - p$. Users must specify a confidence level and measurement accuracy. According to the recommendation in ETTM (1994), the measurement accuracy ($1 - d$) is equal to 99.95 percent. Then the binomial distribution is approximated by the normal distribution according to the Central Limit Theorem. The equation for the sample size estimation is as follows:

$$n = \left(\frac{z \frac{\alpha}{2}}{d} \right)^2 \times p \times q$$

where n = estimated sample size

$\alpha = 1 - $ confidence level

$d = 1 -$ measurement accuracy $= 1 - 0.9995 = 0.0005$

p = probability of a successful transaction

q = probability of a failure transaction $= 1 - p$

z = z-value of normal (i.e., $cdf(z) = 1 - \alpha/2$).

For example, for $d = 0.0005$, $p = 0.9995$, and $\alpha = 0.10$, the sample size is 1,645. It is noted that the sample size is much more sensitive to the measurement accuracy $(1 - d)$ than the confidence level $(1 - \alpha)$.

Electronic Toll Collection System Design Issues

This section describes ten electronic toll collection (ETC) system design issues: communication, accuracy and reliability, compatibility, flexibility, health safety, traffic operations, other operational considerations, serviceability and maintenance, computer system requirements, and environmental conditions.

Communication

A crucial element of any ETC system is the communication between vehicle and roadside (Venable et al., 1995). Other communication links are between toll lane and toll plaza, between toll plazas, and between the toll plaza and the central computer. The communication link must be secure, adaptable, and dependable. This link needs to utilize equipment that is easy to install and functions in all vehicles and under all weather conditions. The mode of communication must also be considered. For example, communications between tags and readers can be carried out by radio frequency (RF), optical/infrared, inductive loop, surface acoustical wave (SAW), dedicated short range communication (DSRC), or Global System for Mobile Communication (GSM) networks; links elsewhere can be hardwired, dial-up telephone lines, or fiber optical cables (Venable et al., 1995).[23]

Accuracy and Reliability

An ETC system's accuracy is important for its credibility and for its revenues (Venable et al., 1995). If the system is perceived to be inaccurate, then the percentage of ETC users may decrease. Patrons do not want to be overcharged or to receive false enforcement notices. Three issues that should be considered when assessing the accuracy and reliability of automatic vehicle

[23] It is important to note the difference between the (standard) RFID and DSRC technologies mentioned above. Historically both of these were the same. However, with the advent of 5.9 GHz band, these technologies diverged somewhat. DSRC is a subset of RFID. DSRC can deliver a far greater data rate and range to wireless highway applications. Also, because of its long read-range, DSRC must be able to operate in a condition of multiple overlapping communication zones – a condition that most RFID systems today can not meet.

identification (AVI) systems are the possibilities of electrical interference, interference from metal oxide windshields, and improper tag installation (Pietrzyk and Mierzejewski, 1993).

Pietrzyk and Mierzejewski (1993) described two causes of electrical interference: frequency range and improper design or installation. When other non-AVI transmitters (such as cellular phones or police and other mobile communications) operate on nearby frequencies, a failure to properly read a vehicle tag may be the result. This cause can be eliminated by obtaining a Federal Communications Commission (FCC) license for a dedicated frequency. However, this is not an easy process. An unlicensed system can depend only on redundancy of transmission to reduce interference; it is unable to ignore or reject any interference that causes problems in operation. An example of an improperly designed AVI system is a circumstance in which the transmitted signal from one AVI lane is overlapped into another lane. This can result in multiple recordings of the same vehicle or in a failure to record vehicles. It can be prevented by careful design of AVI systems and proper selection and placement of antennas. The problem of multiple readings can be minimized by proper design of the toll booth configuration, because the booth can block signals between lanes.

Pietrzyk and Mierzejewski (1993) indicated that less than 2 percent of the nation's vehicle fleet is equipped with metal oxide windshields, but this coating causes disruptions in AVI signals that must pass through the windshield. The disruptions could be minimized if an optional external location for mounting the tag on the vehicle is allowed. As the state-of-practice example, E-ZPass requires exterior tags for vehicles that have windshields with solar ray glass, solar tint, heated or heat reflective windshields, and insulated or Insta-Clear glass. The special vehicle listing is provided on E-Zpass's website at http://www.ezpass.com/static/info/exteriortags.shtml.

The method of tag installation can affect reliability. When tags are incorrectly placed, they may cause misreads. For guaranteed reliability, tags should be permanently mounted by experienced toll agency personnel. In addition, Berry (1993) suggested that the system should be able to detect fraudulent use of tags—for example, the placement of a two-axle tag on a multi-axle vehicle.

Before an ETC system protocol are chosen, the level of accuracy must be determined. If an accuracy rate of 99.95 percent, which is considered a low percentage for peak periods, is desired, then a test of 40,000 to 50,000 observations is required to achieve a statistically valid test (Humphrey et al., 1992). For this accuracy rate of 99.95 percent, the system can malfunction only once per 2,000 observations. This means the reader, AVI, and enforcement systems must attain a greater accuracy rate (Venable et al., 1995).

Compatibility

Compatibility here refers to the ease of cross-boundary usage of the ETC components. Three compatibility types should be considered (Venable et al., 1995). First is the compatibility of the equipment manufactured by different companies, which requires the development of a standard for the communication link between the on-board unit (OBU) and the roadside. The second type is compatibility for cross-agency use, which means that vehicles can use common equipment for other tolling systems. The third type is the use of ETC equipment for other intelligent transportation system (ITS) functions, such as route guidance and automatic parking management systems. However, note that making equipment compatible with ITS purposes tends to increase costs. For example, an ETC system may require a read-only tag, whereas ITS functions require read–write capabilities (Venable et al., 1995).

Flexibility

The ETC system design should be flexible so that the system can be expanded, changed, and improved (Venable et al., 1995). The system needs to include procedures to handle a failure, an accident, or a disabled vehicle that requires lane closure. Lanes should be designed for two payment modes so that if a dedicated AVI lane is closed, vehicles can be re-routed to an adjacent mixed AVI lane. Flexibility also includes different payment methods and tag use (Venable et al., 1995).

Health Safety

Accounting for safety is an important issue in the design of ETC systems. The effects of radiation can be divided into three categories: ionization, heating effects, and biological effects. Ionization occurs only for very high frequencies such as X-rays and never occurs at radio and microwave frequencies. Heating effects occur only for very high power densities and never occur for the power levels used in AVI systems. Only the third category—that is, biological effects—is an important consideration in AVI systems. The probability of harmful biological effects is a function of the frequency and power density of electromagnetic radiation. The frequencies used in AVI systems range from very low to about 3 GHz, which are not usually considered harmful. The more important factor is the power density, which is a function of both the power level of the transmitter and the type of antenna used. Pietrzyk and Mierzejewski (1993) discussed an extreme example and concluded that the power densities encountered in AVI systems were far below all accepted national standards. Hence, the AVI system can be considered one of the safest applications of electromagnetic energy.

Traffic Operations

The presence of an ETC system has a significant impact on traffic operations. Toll plaza lanes can be characterized into five basic lane types: attended automatic, mixed AVI, dedicated AVI, and express AVI. A toll collector handles all toll transactions for attended toll lanes. Automated lanes collect tolls by coin machines. Mixed AVI lanes combine AVI with either manual toll collection, automatic toll collection, or both. Dedicated AVI lanes are contained within conventional toll plazas but permit AVI patrons only. Express AVI lanes are physically separated from all other toll lanes types and enable free-flow speeds (at least 55 mph).

The issue of dedicated versus mixed AVI lanes depends on four basic characteristics: capacity by lane type, the relationship of speed to capacity, levels of AVI participation, and thresholds for toll plaza lane configurations.

Pietrzyk and Mierzejewski (1993) calculated the average capacity and average speed of the five toll plaza lane types based on observations and counts from existing toll facilities. Their statistics are shown in Table H1.3. Note that average capacities are typically reduced by 10 to 20 percent when gates are used on automatic lanes, and the inclusion of AVI has the potential to increase lane capacity by 50 to 160 percent.

Table H1.3: Average Capacity and Average Speed on Toll Plaza Lane Types (Pietrzyk and Mierzejewski, 1993)

Toll Plaza Lane Type	Average Capacity (vehicle/hour)	Average Speed (mph)
Manned	350	2.5
Automatic with gates	500	5
Mixed AVI with no gates	700	7
Dedicated AVI	1,200	15
Express AVI	1,800	55

From Table H1.3, it can be seen that speeds increase as preferential treatment for AVI increases, owing to less restriction in toll processing. Note that express AVI lanes retrofitted into a conventional toll plaza will need significant additional attention to planning, design, and right-of-way.

It is difficult to estimate the projected level of AVI participation; however, varying AVI participation levels have effects on toll plaza lane requirements. From past experiences, a greater amount of AVI participation can be achieved with an additional cost for marketing or publicity. Pietrzyk and Mierzejewski (1993) showed the results from more than 100 simulation model runs for conventional lanes only and for conventional lanes with AVI to determine the maximum potential of plaza lane reduction at the same volume levels.

With the knowledge of capacity by lane type and the relationships between lane reduction and percentage of participation in AVI at different volumes, the ideal toll plaza configuration can be calculated via simulation. The toll plaza is considered ideal when the queue length is at most 300 ft. A simulator can be used to determine the least number of both conventional only and conventional with AVI lanes. Pietrzyk and Mierzejewski (1993) showed the results of more than 100 simulation model runs to determine ideal configurations. Some thresholds for toll plaza lane configurations can be inferred and are shown in Table H1.4.

Table H1.4 Volume Thresholds for Automatic Vehicle Identification Implementation, Peak Direction (Pietrzyk and Mierzejewski,1993)

Initial Consideration for AVI Lane Type	Highest Single Peak-Hour Volume (vehicle per hour)
Mixed AVI	3,000
Dedicated AVI	5,000
Express AVI	7,000

Other Operational Considerations

The following four operational considerations are required for the evaluation of an ETC system: vehicle classification or axle count verification, toll collector safety, gates, and signing/channelization (Pietrzyk and Mierzejewski 1993).

Vehicle classification or axle count verification to determine fare requirements is performed in two parts. The first part is accomplished by visual classification, and the second part is accomplished by using treadles to count axles to verify the visual classification. Inefficiencies can result from toll collector error and malfunctions of treadles. Automatic vehicle classification systems can improve the accuracy of vehicle classification. Note that the vehicle classification systems that count axles work only when the vehicle is moving at a relatively constant speed (Davies et al., 1991). ETC or AVI provides an audit trail for each AVI-equipped vehicle, so toll collector errors and fraud on AVI transactions can be reduced.

If not designed properly, implementing of AVI within a conventional plaza can create safety problems for toll collectors when arriving and departing from toll booths, owing to higher traffic speed. Solutions include the provision of pedestrian tunnels or overhead walkways, safe access for maintenance purposes by means of separate parking areas, and an increase in the number of toll gates.

The processing time of each transaction can be saved by 1 to 1.5 seconds in lanes without gates. Gates can create backups and delays when malfunctions occur. If statues allow photographic enforcement, gates should not be used for deterring violators.

Traffic officials have established procedures for traffic control (i.e., signing, pavement stripping, and channelization) and traffic regulations (i.e., speed and passing zones), which have been applied to conventional toll plaza configurations. These procedures are intended to provide for the safety of the patron and toll collector. With the implementation of AVI, the following operational criteria must be incorporated into the design: advanced signing and channelization to safely accommodate AVI traffic, site-specific speed limits, and transition requirements of diverging and merging AVI traffic.

Serviceability and Maintenance

On the basis of very limited data, Pietrzyk and Mierzejewski (1993) estimated the maintenance costs per lane associated with AVI. These costs appear to be approximately 10 to 20 percent less than those for conventional toll lanes because the majority of operational costs, which consist of employee salary and related costs, would not be relevant with AVI lanes.

Computer System Requirements

Pietrzyk and Mierzejewski (1993) described the system features of the latest designs being implemented at new or retrofitted toll facilities. They stated that these systems are composed of four parts: a host computer, external data storage, network interfaces, and high-speed printing. The host computer connects to computers located at every toll plaza, which are in turn connected to lane controller computers, forming a hierarchical configuration. These smaller plaza and lane computers are usually of the same platform as the host computer—that is, they are supplied from the same vendor. Pietrzyk and Mierzejewski (1993) stated that the industry was starting to see the first implementations of a decentralized, nonhierarchical system.

It is essential to evaluate different host computer systems on the merits of various features, such as processing power, size, expandability, networking capabilities, software compatibility, and cost. Also, the merits of a single- versus multi-processor configuration should be considered. With a dual processor configuration, maintenance, hardware upgrades, and software upgrades can be performed on one processor while the other is functioning.

External data storage is another vital system feature. An enormous amount of data generated at all levels of the system must be accommodated. At the host location, the disks should hold three to six months' worth of data. Data stored at this level include transaction data files, maintenance records of the plaza, event logs, security files, and AVI accounts list. Note that the transaction file should be stored in duplicate locations (shadow recorded) for protection, and data must be synchronized with the host data to ensure recovery in case of a malfunction. At the lane controller level, adequate storage is necessary for two or three years. Data stored at this level include transaction files, maintenance data files, and AVI account verification files. The greatest shortcomings in the industry are inadequate storage space in the lane controller computers (Pietrzyk and Mierzejewski, 1993).

Network interfaces enable communications, such as the constant updating of file data and the passing of transactions, from one processing level to the next. Network interfaces range from local area networks (LANs) for attached devices or lane controllers to wide area networks (WANs) that tie together all the plazas in a system (TRC254, 1983). However, fiber optic cable systems provide the most flexibility; thus, newer facilities should consider the employment of such systems rather than leased circuits for wide area coverage.

Environmental Conditions

When evaluating system placement, environmental conditions should be considered (Venable et al., 1995). Vehicles may travel in a wide variety of environmental conditions, including excesses of dirt, wind, humidity, oil, snow, water, ice, de-icing chemicals, and spilled commodities. Temperatures extremes for equipment operation range from over 38 °C (100 °F) in the summer to −18 °C (0 °F) in the winter. Some video enforcement systems are sensitive to extremely cold weather, and AVI systems that use vertical sound waves may be distorted by strong wind (Venable et al., 1995). Humphrey et al. (1992) indicated that there has been very little unbiased documentation on ETC equipment in various weather conditions.

Institutional and Implementation Issues

This section describes eleven institutional and implementation issues: operational and accounting functions, ownership arrangement of electronic toll collection (ETC), cost considerations, patron payment options, system benefits, market identification and perception surveys, enforcement, security, privacy, equity, and other legal issues.

Operational and Accounting Functions

There are four important operational and accounting functions for ETC systems: tracking toll revenues, processing patron account information, generating relevant management and operational reports, and safeguarding toll system assets.

Pietrzyk and Mierzejewski (1993) described an overview of manual, automatic, and express AVI collection processes based on the E-470 Public Highway Authority in Denver, Colorado. The collection process consists of four sections: physical flow of money, data processing, data records, and audit control point. The physical flow of money is done electronically for the express AVI process, and details for the other two processes can be found in Pietrzyk and Mierzejewski (1993). The data processing system is an important auditing tool used in verifying and recording each step in the toll collection process. Data records are generated after each step of the collection process. These records provide the necessary transaction details to the internal and external auditors of the AVI toll system to complete the audit reports. Audit control is defined as having all individual transactions classified correctly, with collected money reconciled to transactions and totals (Berry, 1993). During audit control, irregular or unusual transactions may occur as a result of invalid accounts, unread/misread tags, class discrepancies, and vehicles being towed. For towed vehicles, tag reading can be unreliable; that is, an on-hook vehicle's tag would be read but the tag of a vehicle on a flatbed wrecker would not be read (Kraft, 1990).

The processing of a standard AVI vehicle takes fractions of a second to complete. The patron account information is processed as follows. The AVI system detects an approaching AVI-equipped vehicle and prepares for the transaction. As the vehicle passes over the lane treadle, the system registers the vehicle by reading and identifying the assigned AVI code. Then the system verifies that the patron's account balance is sufficient to cover the toll charge, and the vehicle is classified for audit and tolling purposes. At this time, the system also registers lost or stolen tags or below-balance accounts. If the AVI code is associated with a valid account, the lane's traffic signal turns from red to green. Otherwise, the light remains red, indicating a misread, a lane violation, or a problem with the patron's account. This requires the manual payment of the toll by the patron either in the automatic coin machine or to a collector. When the vehicle is cleared to leave the toll plaza, the system automatically updates the patron's database files and other associated files. All lane transactions are detected and recorded regardless of whether that the lane is in operational mode or not.

Pietrzyk and Mierzejewski (1993) compiled a list of reports that can be generated using data contained in the AVI computer system's database. This can be varied depending on the agency's requirements. The list of reports is as follows:

- individual lane, plaza, and systemwide transaction and status reports,
- individual lane, plaza, and systemwide accounting and audit reports of toll revenues,
- maintenance and diagnostics reports for system equipment,
- traffic statistics and traffic management reports,
- daily and monthly system accounting reports,
- daily and monthly AVI service center reports,
- daily and monthly personnel status and payroll reports, and
- daily and monthly system audit reports.

Measures to safeguard revenues are necessary because revenue collection systems are frequently targets of abuse. Several key safeguard features are described as follows. Surveillance cameras have been put in place to record lane violations and possible collector violations. Computer hardware and software networking characteristics of the surveillance camera form a considerable safeguard against system failure. System-generated equipment status reports and diagnostic and maintenance reports monitor and detect possible equipment failures. In addition, the computer system should have sign-on access procedures for all levels of personnel with predetermined system access levels to provide additional security for the system.

Ownership Arrangement of Electronic Toll Collection

In general, toll agencies integrate their desired administrative arrangements into their bid specifications (Venable et al., 1995). There are three possible ETC system ownership arrangements: the vendor-own-and-operate plan, the agency-own-and-operate plan, and the lease agreement (the combination of the other two plans). In the first plan, an independent contractor is hired to administer the ETC program. The agency gives the contractor responsibility for equipment installation, operation, administration, and maintenance. Usually, there is an agreement or contract between the vendor and the agency stating conditions, terms, and responsibilities. In the second plan, the agency operates the system independently after purchasing an ETC system. The agency has complete control over the ETC system and, thus, is responsible for the successes and failures. In the third plan, there are several ways to arrange the lease agreement. One option is that the agency may lease the equipment with a maintenance contract provision but handle all operations internally. The agency may retain control over any aspect considered appropriate (Venable et al., 1995).

Most vendors are flexible with respect to the administrative arrangement; however, the ability of a toll agency to select an ownership arrangement is controlled by the agency's charter. For example, an agency is not permitted to subcontract the responsibility of fare collection. This would limit the ability to subcontract ETC under the vender operation scenario. Pietrzyk and Mierzejewski (1993) discussed issues to be considered before entering into the any of the three arrangements, as shown in Table H1.5.

Table H1.5 Issues for Three Ownership Arrangements of ETC

Ownership Arrangements	Issues
Vendor-own-and-operate plan	o The agency does not own the AVI system. o The agency would be responsible for monitoring and evaluating the performance of the contractor. o If the agency were not satisfied with the AVI system, it would be very costly to remove the system because the agency does not own the AVI equipment. Also it depends on the negotiated contract. o The agency can define performance objectives and standards that must be met by the contractor. o Typical contractors have significant marketing resources that can increase the potential for maximizing patron participation. o The ability of the agency to collect the correct fares depends on the contractor's records of fares collected. Detailed audit controls would be required if the agency allows a contractor to electronically transfer tolls collected. o Information concerning the AVI users and their billing records could be the property of the contractor and not the agency. Ownership of these records at the end of the negotiated contract is not always clear. o The agency may suffer from an identity problem; that is, the AVI patrons identify with the private vendor and not the agency. o If compensation to the contractor is directly tied to the level of patron participation, then there is some incentive to succeed.
Agency-own-and-operate plan	o The toll agency maintains complete control over the AVI system. o The toll agency benefits from the interest earned on all prepayments and deposits collected as part of the AVI program. o The agency will be fully responsible for the successes or failures of the AVI system. o Different support staff are required to maintain and monitor the AVI system; however, overall the number of staff should be smaller when compared with a conventional system. o Additional training of staff is required as it relates to the production and analysis of the several information and audit reports that the computer system provides as a result of interfacing with the AVI system. o Overall levels of staff may change depending on the system design.

Lease agreement	o The agency definitely assumes ownership of the equipment under most lease agreements. o The agency may not own the equipment over the life of the lease. o A lease agreement is extremely flexible. For example, the agency might be responsible for administrative tasks whereas the remaining tasks are built into the negotiated contract.

Source: Pietrzyk and Mierzejewski (1993)

Cost Considerations

The capital, operating, and maintenance costs associated with the construction and operation of an ETC system as well as various lane types must be considered. The agency should consider the costs for the following five categories: lane construction and right-of-way, equipment by lane type, operating and maintenance expenses, transponders for the different technologies, and computer hardware and software.

Pietrzyk and Mierzejewski (1993) provided cost information based on data from the Florida Office of Toll Operations, Dallas North Tollway, Oklahoma Pikepass, and related industry bid tabs. Note that costs will likely decline when the equipment is purchased in large quantities, and costs vary significantly by region and location throughout the United States.

Patron Payment Options

The agency should consider three areas in evaluating payment systems (Pietrzyk and Mierzejewski, 1993): pre-payment versus post-payment, toll structures, and actual payment methods.

The operational procedures for pre-payment and post-payment are described as follows (Pietrzyk and Mierzejewski, 1993). For a pre-payment ETC system, users establish individual accounts with a prepaid balance; the toll amount is deducted from the user's account balance when the vehicle passes through a toll lane. A post-payment system is based on a billing process. Users are charged based on actual use of the toll system in the past month. Different implementation costs and issues must be considered when evaluating pre-payment and post-payment toll systems. Pre-payment systems require the establishment of locations for opening and replenishing AVI accounts, and costs are incurred with the construction, operation, and maintenance of the locations. Post-payment systems include additional operational costs for bill collection (Pietrzyk and Mierzejewski, 1993). Another payment system is the joint clearing-house approach (Venable et al., 1995). This system uses a reimbursement system that allows toll-paying customers to maintain only one account for all participating agencies.

There are three toll structure options: charging premiums in addition to existing tolls, discounting existing tolls, and keeping the toll structure the same (Pietrzyk and Mierzejewski, 1993). For the first option, it is believed that users should pay an extra charge for these special services. For the second option, it is argued that users need to be encouraged to use AVI by offering discounts on services, and increased patron participation resulting from discounts would fully offset declines in revenue. For the third option, it is contended that implementation problems would not exist and governing legal documents would not need to be reviewed for compliance. Premium and discount toll structures are found to be equivalent for ease of implementation and associated costs. The costs include an extensive marketing campaign to educate potential AVI patrons on the new toll structure and additional signage detailing the new toll structure. Note that historical data concerning transportation demand elasticity should be considered. For work trips, demand is relatively inelastic when associated with price. An inelastic demand implies that a 1 percent change in price will result in a less than 1 percent change in the quantity demanded. Thus, it is expected that a minor toll discount would not significantly increase participation in the AVI system despite the positive reaction to discounted tolls in the survey research (Pietrzyk and Mierzejewski, 1993).

AVI-generated tolls can be paid by cash, check, electronic funds transfer, or credit card (Pietrzyk and Mierzejewski, 1993). The use of electronic funds transfer and credit card does not require the handling of money, so the operational costs are reduced and implementation and maintenance of the payment program are simplified (Pietrzyk and Mierzejewski, 1993).

System Benefits

Pietrzyk and Mierzejewski (1993) discussed many benefits resulting from the implementation of an AVI system: throughput efficiency, payment alternative for patrons, increase in patron satisfaction and loyalty, reduced noise pollution and emission, security against loss of funds, improved accountability, reduced construction and operating costs, potential for increased revenue, and psychological benefits.

Market Identification and Perception Surveys

A user perception has to be conducted to identify the most effective AVI marketing strategies and technology features (Pietrzyk and Mierzejewski, 1993). Given the socio-economic and travel characteristics of the area, the potential market for ETC use varies with each installation.

Enforcement

AVI lane violations are important for both users and agency (Pietrzyk and Mierzejewski, 1993). The violations can cause the delays and inconvenience to other users and cause lost revenue to the agency. A high-speed video camera is essential for successful ETC systems to deter violators. Many states, such as Colorado, Florida, and Illinois, have passed laws allowing AVI violators to be legally identified and cited based on videotape evidence. However, some states such as New Jersey turned down legislation enabling photo enforcement. State laws that allow pictures generated from remote video cameras to support prosecutions are not uniform. Illinois was the first state to win conviction of a driver using this evidence. Photo enforcement has been used in Europe for two decades. Zurich, Switzerland added a photo enforcement component to its ETC system in 1983. An important part of the AVI enforcement system is camera equipment. The agency should carefully review the specifications. All lanes typically include remote control, high-speed video cameras to record violations regardless of whether the lane is open for operation or not. When a violation occurs, the camera is activated and records the offending vehicle, its license plate, the lane’s traffic signal, and the violation indicator as the vehicle travels over the lane’s exit loop. All video enforcement systems should record on the video picture, date, time, and lane number of the violation. The video picture should be recorded on a computer disk and retrieved when a hard copy is required. Note that the video camera system should also record vehicles with a reported lost or stolen tag, with an account below a minimum balance, with an account that has been suspended, or with an axle classification, that does not match the treadle count (Pietrzyk and Mierzejewski, 1993).

Security

Security must be integrated into the system (Venable et al., 1995). When the tag is delivered to the user, the agency has lost control over the unit. Consequently, the device has to be designed to prevent tampering. There are microprocessors available that can perform crypto-functions needed for safe payment. Messages are encrypted with secret keys and with algorithms to prevent misuse. Before any function is performed with the processor, the tag will be checked for proper encoded authorization (Stoelhorst and A.J. Zandbergen, 1990). The toll plaza and external equipment are all subject to vandalism, theft, accidents, and intentional destruction. Security at these locations is necessary for the preservation of property, personnel and motorists' safety, and revenue protection. One way to increase security is to require that all staff and visitors use identification badges (Venable et al., 1995). ETC enables the automatic debiting and electronic funds transfer, so the toll agency operators do not handle cash transactions (Pietrzyk and Mierzejewski, 1993). As AVI participation increases, the total revenue collection process will be automatically performed more. Reconciliation of each transaction can become more readily isolated and checked. Audit trails generated by system software will deter collector fraud and misreporting (Pietrzyk and Mierzejewski, 1993).

Privacy

To protect the privacy of individual vehicle users, the toll agency must establish appropriate safeguards and guidelines on the control and use of ETC information (Pietrzyk and Mierzejewski, 1993). However, note that according to surveys conducted among San Francisco Bay Area motorists, only 7 percent of the respondents indicated a strong concern that electronic tags could permit tracking of their vehicle. The Electronic Communications Privacy Act (ECPA) was adopted in 1986 to protect wire or electronic communications from illegal interception by unauthorized third parties. This act makes three things possible: standards and procedures for court-authorized electronic surveillance, regulation of when electronic communication firms may release information, and legal protection of the privacy of stored electronic communications from outside intruders and unauthorized government officials. Pietrzyk and Mierzejewski (1993) stated that a major revision of the ECPA was under consideration, and it might include privacy protection for ETC travelers—that is, drivers who do not want to be tracked or photographed can always use the free facility or pay in cash.

Equity

The toll agency bond indenture must be reviewed carefully to assess the legal options that can be offered to toll patrons (Pietrzyk and Mierzejewski, 1993). If it can be proven to the bond holders that projected revenue will not be jeopardized, then payment and transaction options can be created with their approval vote. In selecting a method of payment, patrons should not have to face discrimination. For example, if the only form of payment or account replenishment is via a major credit card, as in Denver, some potential patrons may be excluded from participation. If patrons are required to pay an additional transaction toll or get a reduced toll fare, further discrimination may result (Pietrzyk and Mierzejewski, 1993).

Other Legal Issues

There are four other legal issues that could affect ETC deployment: product liability and other tort liability, antitrust, procurement, and intellectual property rights (Pietrzyk and Mierzejewski, 1993).

Private sector designers and manufacturers may be significantly deterred from the development and introduction of new technologies to the transportation system by liability doctrines and practices. The cost to the private sector is raised by the exposure to risk of expensive product liability suits. General vehicular accident cost may fall on ETC product manufactures.

Antitrust law may restrict collaborative research. Although there is increased flexibility for U.S. companies to work cooperatively, consideration of additional changes may be needed to allow firms to compete more effectively in the ETTM industry. The toll agency should improve the way to effectively fund productive, creative research and development.

It is widely believed that procurement and government contracting requirements are too complex and time consuming, often constraining effective and timely implementation. The toll agency should consider whether current contracting and procurement practices support or delay the goal.

As part of the Intelligent Vehicle Highway System (IVHS) development process, many cooperative arrangements among government, the private sector, and universities are expected. These include research consortia and operational test joint ventures. Thus, it is essential that understandings and agreements regarding rights to intellectual property be reached at the beginning of each project. All parties must understand the policy for copyrighted material including computer software. The nonfederal party generally may copyright the material developed under the funding agreement, given that the federal agency reserves a royalty-free, nonexclusive, and irrevocable license to reproduce, publish, or use the copyrighted material for government purposes (Pietrzyk and Mierzejewski, 1993).

Appendix H2: Technology Experience from Different Countries

This appendix describes the CP experiences from different countries around the world.

Experiences from Europe

This section reviews some of the ETC experiences in Europe. We review ETC systems from six countries: Italy, Finland, Sweden, the Netherlands, Germany, and Switzerland. Most of the review is based on the FHWA report by Clinger et al. (1997) and Porter et al. (2004).

(i) Toll Collection System in Italy (Pasquali, 2002)

TELEPASS system was developed in 1989 and was initially deployed on the Italian Autostrade network in 1990. This is considered the world's first automatic toll collecting system to enter service. TELEPASS is based on 5.8 GHz beacons and in-vehicle transponder technology together with the use of a non-contact pre-payment smartcard. TELEPASS provides a flexible approach to toll collection and allows the system to offer a real-time, non-stop payment facility, which substantially increases the throughput of a toll plaza lane without the need for physical barriers. There are currently over 200 toll lane stations installed and in use and some 2.7 million on-board units. Even after 12 years, this is considered the most widely used integrated system in use worldwide.

(ii) Electronic Toll Collection in Finland (Clinger et al., 1997)

The Finnish Ministry has developed programs for automated electronic payment and debiting systems since the mid-1980s. The Payment System Steering group was formed in 1991 to study the electronic payment systems, and this became the basis for planning, designing, and implementing of the debiting systems currently in use. Some of the smart card technologies conducted in Finland are reviewed here. One primary consideration in the design of the ETC systems in Finland was user friendliness.

Finland has used smart cards (credit card sized) that have an input/output interface and one or more circuits incorporating memory and possibly control logic or a microprocessor. The characteristics of these cards have been standardized by the International Standard Organization (ISO). Finland has also incorporated standards from the telecommunication industry. The specifications of the policy for developing this system were given in an eleven-point operational plan. The different parts of the plan are as follows: general description, security architecture, cards, security module, interfaces of application programs, application architecture and the information content of the payment device, equipment, data communication interfaces, maintenance, quality control and acceptance procedures, and distribution and management system.

On the basis of this plan, smart card trials were conducted in the towns of Kotka and Seinajoki in the Helsinki Metropolitan Area and in the cities of Turku and Oulu. The experience was positive, and all the trial systems with the exception of Helsinki Metropolitan area were implemented by December 1997.

An interesting concept introduced by Finland is the concept of City Card. This is a smart card that can be used within specific city limits by residents receiving services provided by the city. It can be used for an array of services, including fees for tennis courts, swimming pool use, parking fees, taxicab rides, public transportation fares, and so forth. The responses from the users of this card were positive, and the benefits of this system for the transport authority included reduction in ticket printing and handling costs, improved efficiency for payment clearing and fund transfers, reduced operating costs, improved quality of business operations data, and enhanced flexibility of customer services. Other indirect benefits included technical and institutional coordination and integration that must take place for efficient implementation of these systems. However, at the time of this report, there were still no studies on issues relating to security, privacy, and information exchange among related parties using this technology. This is the line of work on which Finnish authorities are concentrating for improving the overall level of service.

(iii) Electronic Toll Collection in Sweden (Clinger et al., 1997)

The following were the prerequisites listed by law for collecting tolls in Sweden.

1. The system must have an anonymous payment option (for privacy).
2. Manual payment must be possible.
3. Less than 7 percent of the collected tolls must be spent on operation.
4. The system in Stockholm must be interoperable with the eventual Gothenburg System.

The tolls in Sweden are governed by the Dennis Agreement according to which toll collection is considered a tax and not a user fee. The current plan in Sweden is to use an electronic purse system, with microwave communication, to allow users to add money to a smart card type device in order to utilize the ring road in Stockholm. The Gothenburg tested system, known as Automatic Debiting for Sweden (ABSW) is based on a smart card that is credited with a prepaid amount and inserted in a tag fitted to each vehicle. The tag on each vehicle establishes the communication with the roadside using a magnetic reader, and the appropriate toll is debited from the card immediately and automatically. The vehicle's license plate is photographed if no payment is made. Furthermore, vehicles that do not have smart card technology are photographed for later payment. In the future, Sweden plans to integrate other services on the smart card like the system in Finland, such as parking and public transportation.

(iv) Electronic Toll Collection in the Netherlands (Clinger et al., 1997)

According to the latest FHWA report of December 1997, there were no toll roads in the Netherlands. However, they have come up with a new pricing policy to influence automobile usage, based on scope, time, place, and method of transport. Smart card technology is being considered as a method of implementing eventual pricing strategies by improving and simplifying payment functions. The authorities recognize that automatic vehicle identification and tracking are key technologies for enabling the flow of information and goods to be integrated.

(v) Electronic Toll Collection in Switzerland

Switzerland's heavy vehicle toll system is used by heavy vehicles weighing at least 3.5 tons transporting goods in Switzerland and Liechtenstein. The fees are calculated by multiplying a vehicle's maximum weight, distance traveled, and an emissions-dependent fee. The ETC system employs the global positioning system (GPS) and dedicated short range communication (DSRC) technology for AVI and vehicle miles traveled (VMT). Every vehicle subject to the fee is required to install an on-board unit (OBU) connected to three interfaces: a tachograph, DSRC, and GPS receiver. The DSRC interface switches mileage collection on and off at border crossings. The tachograph provides mileage information. The GPS interface provides internal monitoring of mileage and makes sure that the OBU clock keeps exact time. It also ascertains whether a vehicle is inside or outside Switzerland. There is a manual intervention for this system. Each month, vehicle drivers declare their vehicle data either by sending in data storage chipcards, which are supplied for use with the OBUs, or by using chipcards to read declarations and transmit data by modem or internet. (Clinger et al., 1997)

(vi) Electronic Toll Collection in Germany

Germany's Toll Collection System is a distance-based ETC for heavy vehicles with a gross vehicle weight of at least 12 tons. The system employs an OBU with GPS, DSRC, and the gyroscopic backup system. The GPS is used to collect distance traveled and to identify the roads used. The Global System for Mobile Communication (GSM) network is used to handle the communication of this information to the central office in order to initiate the payment process. The DSRC system is used for enforcement, together with optical character recognition systems. The gyroscopic backup systems are used when GPS signal loss occurs (Clinger et al., 1997).

Experiences from Asia

In 1975, Singapore introduced a congestion-pricing scheme (called the Area Licensing Scheme) in its central business district (CBD) area during weekdays. The eventual failure of these manual systems was attributed to confusion about licenses, traffic queues at the toll booths, and the labor costs involved, but as a consequence research on ETC was launched in Singapore as early as 1989. The ETC experience and some of the recent congestion management strategies are briefly discussed below.

Electronic Toll Collection: The Singapore Experience

Electronic road pricing (ERP) was started in 1998 to electronically monitor vehicles entering a restricted zone, in order to ensure a smooth traffic flow. This system is capable of automatically imposing a demand-sensitive congestion toll on every vehicle without requiring vehicles to slow down or stop. One of the limitations of the ERP systems tested in the mid-1980s in Hong Kong and the Netherlands was the issue of public privacy. Singapore, however, overcame the privacy and billing issues by using less intrusive systems with automatic toll collections (ATCs). Langmyhr (1999) described the approach, which is similar to that used for Norway's toll ring. Illegal entry into a restricted zone (without an appropriate CashCard) results in a $40 fine. Motorists insert a CashCard into their in-vehicle units (IUs) when on the road. Each IU costs about $90 and is installed in front of the driver's seat. These are programmed to contact the computers on the toll gantries, and the dynamic toll is automatically deducted. The IUs can be swapped among different vehicles, and the toll is collected based on different vehicle types.

There are several advantages of Singapore's ERP system. Uninterrupted traffic flow conditions are achieved throughout the day, and the system can charge users on the basis of the time of day. Legal proof of violations comes from video photos including all vehicle details. Concerns about CashCard bribery and forgery are minimized, because all processes are automated. Differential pricing is possible based on actual external costs such as trip length, time of day, route followed, and vehicle type. Furthermore, motorists can be made aware of the true costs of their driving according to time of day and congestion levels.

There are some ERP issues currently under consideration by transportation officials in Singapore that might be relevant to other ERP installations. For instance, CashCards implemented in Singapore must be placed into the IU 10 meters before the first gantry in order to communicate with the computers. To circumvent this problem, the traffic agency responsible for this issue is considering the option of intelligent vehicles with the ERP technologies directly installed. However, this project is still in development stages. In addition, it remains difficult to achieve accurate ERP rate changes based on changes in traffic conditions. It has been observed that in peak hours this issue has sometimes led to unnecessary bottlenecks in other parts of the road network.

Although ERP has produced less revenue than manual systems in the short term, the Singapore government is confident that as travelers become familiar with the ERP system they will accept and use it to a greater degree. To ensure the success of this system, officials have realized that they need to upgrade the transportation system continuously. To complement the ERP system, a private sector bus system has been proposed. It was intended that by 2001, this bus system would feature electronic display panels at major bus stops to inform passengers when the next bus would arrive. Furthermore, the Singapore government is also considering alternate strategies of congestion management (Goh, 2002). Two of the most promising systems are briefly elaborated here. First, the Green Link Determining System uses loop detectors at signalized junctions to collect data and monitor the signal coordination—that is, they allocate the green time at junctions where the traffic flow is heavier. Second, the Expressway Monitoring and Advisory System (EMAS) use a state-of-art monitoring system with a series of high-technology cameras to detect accidents or other conditions that may hinder traffic flow. EMAS enables on-site monitoring of traffic conditions, which allows motorists to change their routes in an on-line fashion.

Experiences from North America

ETC systems have been implemented in some states in the United States. Examples include the E-ZPass system in the Northeast United States and California's FasTrak System. At the Albany International Airport in New York, drivers can use E-ZPass to pay for parking. Fewer cars waiting to pay means less congestion and faster turnaround for people who need to park. E-ZPass also is being tested as a payment method for fast food at two McDonald's restaurants on Long Island. In another application being tested in Maryland, long-haul trucks are being given electronic tags that work not only as toll tags but also as prescreen registration devices so the drivers can bypass weigh stations. These systems employ the radio frequency automatic vehicle identification (RF AVI) technology. The users are required to install RFID tags on their vehicles, and at the electronic toll booths, the suitable tolls are automatically deducted from associated accounts. These systems employ both vehicle weight sensors and video cameras for deterring violators. Note that two sections of the FasTrak system have implemented the dynamic congestion-pricing scheme: one section (8 miles of IH 15 in San Diego County) based on actual traffic congestion conditions, and the other section (State Route 91 in Orange County) based on the time and day of the week. These dynamic congestion-pricing sections also employ the RF AVI technology (Porter et al., 2004).

Experiences from Australia

ETC technologies were recently implemented in the city of Melbourne after the Melbourne City Link Project was completed in 2000. Multi-lane free-flow ETC was built, and the tolling configuration is based on an open or screenline strategy, which permits future variations to be developed (Lay and Daley, 2002). The ETC and the video enforcement were established by Combitech. This works in a way similar to that of typical ETC, as was explained previously. With regard to the enforcement system, a video camera captures the front identification number of each vehicle that passes under the gantry. When needed, the optical character reader (OCR) records the registration number. If the tag transaction is successful, the video record is deleted. The system is designed so that any doubtful assignments are made in favor of the customers (Lay and Daley, 2002). One important distinction from the state of art is that the OCR checking and customer bias procedures are done off-line and not in real time. The video does not allow car occupants to be distinguished.

Appendix H3: Key Steps and Intermediate Results from ELECTRE IV Algorithm

Details of the Evaluation Algorithm: ELECTRE IV

The ELECTRE IV algorithm essentially ranks a set of alternatives based on a number of factors (such as cost or ease of enforcement), which have been translated into some quantitative values that can be compared across all of the alternatives. Unlike many similar algorithms, ELECTRE IV does not use weights for the different criteria. This avoids the problem of trying to quantify the relative importance of criteria that may be very different in nature. Instead, the modeler chooses which criteria are to be used to form outranking relations, and each of these is treated equally. Thus, essentially, all criteria have a form of equal "weight" when determining the weak and strong outranking relations (which are in turn used to form the ranks in the two ranking procedures). However, what is counted are the number of criteria with which one strongly or weakly outranks the other. The exact magnitude of the difference is of no concern as long as the strong/weak preference relations are the same.

ELECTRE IV defines strict and weak preference relations based on each criterion – (For instance, Alternative A may be weakly preferred to Alternative B when considering costs, but Alternative B may be strictly preferred to Alternative A when considering ease of enforcement.) Based on these preference relations, the alternatives are ranked using two similar methods, and these ranks are averaged to form the final ranking of the alternatives, which is the output of the algorithm. Despite the significant theoretical work underlying ELECTRE IV, its application is straightforward once the threshold values that define the preference relations are chosen. It is this latter step which requires the most thought of those using the algorithm. For each criterion, one must decide by how much two alternatives need to differ to say that one is weakly (or strictly) preferred to the other.

Established without any weighting of the criteria, the ELECTRE IV method (Roy and Hugonnard, 1982) is based on three principles: pseudo-criteria, outranking relations, and partial pre-orders. The term pseudo-criterion should be distinguished from a true criterion. For a true criterion, options are of equal merit when their criterion values are equal. Due to the imprecision inherent in the data, the concept of a pseudo-criterion is introduced based on indifference and preference thresholds. These thresholds can be either constant or relative, depending on the nature of the criteria. If the uncertainty, imprecision and indeterminacy grow with a criterion value, then the proportionality hypothesis is justified and the relative threshold should be adopted. Further, a criterion can either be a cost or benefit criterion. For a cost criterion, the lower the criterion value, the higher its merit and vice versa for a benefit criterion. Subsequently, we define the indifference threshold (q_k) and preference threshold (p_k) for benefit or cost criterion k. Note that, for both constant and relative thresholds, q_k and p_k are non-negative, and $p_k \geq q_k$. Denote the non-negative values of criterion k for options i and j as x_{ik} and x_{jk}, respectively. The definition of the relative thresholds follows (Roy and Hugonnard, 1982).

Options i and j are indifferent on criterion k if and only if

$-q_k \times x_{ik} \leq x_{ik} - x_{jk} \leq q_k \times x_{jk}$ for benefit criterion k; and

$$-q_k \times x_{jk} \leq x_{ik} - x_{jk} \leq q_k \times x_{ik} \text{ for cost criterion } k.$$

Option *i* is strictly preferred over option *j* on criterion *k* if and only if

$$x_{ik} - x_{jk} > p_k \times x_{jk} \text{ for benefit criterion } k\text{; and}$$

$$x_{ik} - x_{jk} < -p_k \times x_{jk} \text{ for cost criterion } k.$$

Option *i* is weakly preferred over option *j* for criterion *k* if and only if

$$q_k \times x_{jk} < x_{ik} - x_{jk} \leq p_k \times x_{jk} \text{ for benefit criterion } k\text{; and}$$

$$-p_k \times x_{jk} \leq x_{ik} - x_{jk} < -q_k \times x_{jk} \text{ for cost criterion k.}$$

For constant thresholds, the above definitions are still applicable by replacing the terms $q_k \times x_{ik}$ and $p_k \times x_{ik}$ by q_k and p_k, respectively.

The indifference threshold is employed to account for the imprecision and randomness affecting the input data. To determine such threshold on a criterion, we start from a positive value that is sufficiently small and non-significant, and gradually increase the value until it gets to a point considered the boundary of the difference. To determine the preference threshold on a criterion, we start from a sufficiently large value to ensure unquestionably strict preference, and gradually decrease the value down to the limit value so that the strict preference becomes questionable. This is the boundary between strict preference and weak preference. In our example application, it is considered more realistic to adopt constant thresholds for all criteria, and all considered criteria are cost criteria.

Next, we say that option *i* outranks option *j* when there is sufficient evidence from the comparison of all criteria. The rules for constructing strong and weak outranking relations are described in the following paragraph. The term "partial pre-order" is used to differentiate from the complete pre-order. A ranking structure is called a "complete pre-order" on a set of options if the ranking structure is a complete and transitive binary relation. For example, when the binary relation is the strictly preference relation ($\succ$), the complete binary relation means that for all pairs of options *i* and *j*, either option $i \succ$ option *j* or option $j \succ$ option *i*. For transitivity, option $h \succ$ option *i* and option $i \succ$ option *j*, implies that option $h \succ$ option *j*. Thus, the result from the ELECTRE IV method is a partial ranking that can contain a tie (a group of options with the same rank). The distillation procedure for constructing the partial pre-order is described in detail in the following paragraph.

The ELECTRE IV algorithm is divided into three stages: 1) construction of strong and weak outranking relations, 2) construction of downward and upward ranks by distillation, and 3) determination of final rankings. This algorithm is applied here to evaluate various CP technologies.

Stage 1: Construction of Strong and Weak Outranking Relations

Strong Outranking Relation (R_s)

Option i strongly outranks Option j (O_i R_s O_j) if and only if the following two conditions are satisfied:

1) For none of the criteria, O_j is strictly preferred to O_i.
2) The number of criteria on which O_j is weakly preferred to O_i ($|J|$) does not exceed the number of criteria for which O_i is weakly or strongly preferred to O_j ($|K|$). ($|K|>=|J|$)

Weak Outranking Relation (R_w)

A weak outranking relation can take place only in the absence of a strong outranking relation. Option *i* weakly outranks option *j* (O_i R_w O_j) if and only if at least one of the following two conditions is satisfied.

1) There is not some criterion *k* such that $x_{jk} > x_{ik} + p_k$, and $|K|<|J|$.
2) There is some criterion *k* such that $x_{ik} + p_k < x_{jk} < x_{ik} + 2\times p_k$, and O_i is strictly preferred to O_j for at least one half of the criteria.

Stage 2: Construction of Downward and Upward Ranks by Distillation Procedure
Both strong and weak outranking relations are used to construct downward and upward ranks (*V1(j)* and *V2(j)* for each option *j*). The distillation procedure is employed to construct such ranks, and the difference between these two rankings is explained briefly in Table H3.1. The output of this procedure is the ranking (*V*(*j*)) of each option *j* from the two distillation procedures, as described in Table H3.1.

Stage 3: Determination of the Final Rankings
The average values of *V1(j)* and *V2(j)* for each option *j* are used to determine the final rank. (Goicoechea et al., 1982):

$$MV(j) = 0.5\times\left(V1(j)+V2(j)\right); \text{ for all } j$$

Note that more than one alternative can have the same rank; and other factors not included in the model can be used to resolve any ties.

Measures of Performance for Evaluating CP Technologies

There are various important measures for evaluating and comparing CP technologies. We divide these into four categories:

(i) Economic Measures
(ii) Operational Measures
(iii) Impacts, Integration and Flexibility
(iv) Other Measures

These performance measures represent the benefit of installation of a particular technology from both the operator and users' viewpoints. Although, not entirely comprehensive, the measures listed below capture key evaluation parameters.

- Economic Measures:

  Cost – This set of performance measures includes the overall installation, operation and maintenance costs. The overall cost of the technology can be measured in terms of the following parameters:

(1) Technical life expectancy of the technology
(2) Labor, operating and maintenance costs of the technology
(3) Secondary costs incurred by placing the technology (e.g. are there any extra costs in construction, like street changes and increases in number of lanes)

- Operational Measures:

(4) Reliability in detection of vehicles (other parameters could include how much time elapses between technology disruptions, their frequency, the ease of repair etc)
(5) Ease of installation
(6) Ease of replacement in times of failure
(7) Simplicity of use
(8) Ease of Enforcement

- Impacts, Integration and Flexibility:

(9) Are there any traffic or environmental impacts associated with the technology?
(10) Can the technology be implemented with the existing right of way?
(11) How easy is it to integrate the proposed technology with existing technology?
(12) Ease of integration with preferred or common payment methods (credit cards, AUTOPASS, debit cards etc)

- Other Measures:

(13) Faith in credibility of the organization providing technology
(14) Does the technology have any harmful effects on system users (e.g. does the technology affect the health and safety of the users?)
(15) Availability of suppliers for that particular technology
(16) How well do the technology providers handle privacy issues?

Table H3.1: Downward and Upward Distillation Procedures

Downward distillation procedure	Upward distillation procedure
0. Set $r = 1$	0. Set $r = 1$
1. From the strong outranking relation, determine strengths, weaknesses, and qualifications of all options. The strength of Option j is the number of options that are strongly outranked by Option j. The weakness of Option j is the number of options that strongly outrank Option j. The qualification of Option j is its strength subtracted by its weakness.	1. From the strong outranking relation, determine strengths, weaknesses, and qualifications of all options. The strength of Option j is the number of options that are strongly outranked by Option j. The weakness of Option j is the number of options that strongly outrank Option j. The qualification of Option j is its strength subtracted by its weakness.
2. Find the maximum qualification and the number of options with the maximum qualification (*NUM1*).	2. Find the minimum qualification and the number of options with the minimum qualification (*NUM1*).
3. • If there is only one option with the maximum qualification (*NUM1*=1), this option is ranked r. • If there is more than one option with the maximum qualification (*NUM1*>1), every pair of these options is compared in the strong outranking relation. ▪ If Option j strongly outranks Option i and Option i strongly outranks Option j, then both are ranked r ($V_1(j) = V_1(i) = r$). ▪ If Option j strongly outranks Option i and Option i does not strongly outrank Option j, Option j is ranked r ($V_1(j) = r$).	3. • If there is only one option with the minimum qualification (*NUM1*=1), this option is ranked r. • If there is more than one option with the minimum qualification (*NUM1*>1), every pair of these options is compared in the strong outranking relation. ▪ If Option j strongly outranks Option i and Option i strongly outranks Option j, then both are ranked r ($RV2(j) = RV2(i) = r$). ▪ If Option j strongly outranks Option i and Option i does not strongly outrank Option j, Option i is ranked r ($RV2(i) = r$).
4. Find the number of options with the maximum qualification that are ranked (*NUM2*). If 0<*NUM2*<*NUM1*, then $r = r$+1.	4. Find the number of options with the minimum qualification that are ranked (*NUM2*). If 0<*NUM2*<*NUM1*, then $r = r$+1.
5. Compare the options with the maximum qualification in the weak outranking relation. • If Option j weakly outranks Option i and Option i weakly outranks Option j, then if Options j and i have not been ranked, then both are ranked r ($V_1(j) = V_1(i) = r$). • If Option j weakly outranks Option i and Option i does not weakly outrank j, and if Option j has not been ranked, then Option j is ranked r ($V_1(j) = r$).	5. Compare the options with the minimum qualification in the weak outranking relation. • If Option j weakly outranks Option i and Option i weakly outranks Option j, then if Options j and i have not been ranked, then both are ranked r ($RV2(j) = RV2(i) = r$). • If Option j weakly outranks Option i and Option i does not weakly outrank j, and if Option i has not been ranked, then Option i is ranked r ($RV2(i) = r$).
6.Find the number of options with the maximum qualification that are ranked (*NUM3*). If *NUM2*<*NUM3*<*NUM1*, then $r = r$+1.	6. Find the number of options with the minimum qualification that are ranked (*NUM3*). If *NUM2*<*NUM3*<*NUM1*, then $r = r$+1.
7.The options with the maximum qualification that have not been ranked are ranked r.	7. The options with the minimum qualification that have not been ranked are ranked r.
8.If all options are ranked, stop. Otherwise, change the strong and weak outranking relations by deleting Options that are ranked.	8.If all options are ranked, go to Step 10. Otherwise, change the strong and weak outranking relations by deleting Options that are ranked.
9.$r = r$+1, and go to Step 1.	9. $r = r$+1, and go to Step 1.
	10.Find the maximum of *RV2*. (*maxRV2*)
	11.$V2(j)$ = 1+*maxRV2*-$RV2(j)$; for all j.

Key Recommendations for Choice of Technology in the Application of Congestion Pricing

In this section we demonstrate the ELECTRE IV algorithm on a subset of technologies that are commonly used in CP demonstrations. The different technologies used for evaluation are:

(i) Manual Toll Booths (MTB)
(ii) ANPR – Automatic Number Plate Recognition
(iii) DSRC – Dedicated Short Range Communications (specialized RFID[24])
(iv) GPS – Global Positioning Systems
(v) Infrared Communications (IR)
(vi) RFID – "smart" low-cost Radio Frequency Identification

The values of the identified performance measures are shown in Table H3.2. These values are imputed from the most recent CP demonstration projects in Europe (PRoGReSS) as described in section 5. Out of the sixteen criteria identified, we use the 10 best in the ELECTRE IV framework. These are arrived at by not considering criteria that have the same value for all technologies (e.g., criteria 14 and 15). Some of the other criteria for which the values could not be imputed from the demonstration projects were not considered in the evaluation. For this example, we applied criteria 2, 3, 4, 5, 6, 7, 8, 10, 12 and 16. The constant indifference and preference threshold values are shown in Table H3.3.

A few key points need further elaboration. (1) Most of these criteria values are based on the recent demonstration projects in Europe (PRoGReSS) and past reports. For example, we know that ANPR/DSRC enforcement is better than both manual toll booths and GPS. A numerical value is imputed based on the demonstration project results. The values assigned are subjective; however, the robustness of the final results are verified by performing a sensitivity analysis. This is described towards the end of this section. (2) Some of the criteria values not known have been assumed in this study. As better information becomes available, model parameters can be refined. For example, we do not know how well or easily RFID systems can be enforced but have assumed such enforcement to work well, based on information from recent experiments and other, related applications (Juels, 2003). (3) The values for the criteria 2, 3, 4 and 7 are measured on a relative scale (with 1 for best, and 10 for worst), whereas the criteria 5, 6, 8, 10, 12 and 16 are ordinal rankings – from 1 (best) to 4 (worst).

[24] A few technical differences exist between the standard RFID and DSRC technologies: DSRC is claimed to deliver a far greater data rate and range to wireless highway applications. Compared with existing RFID toll applications, DRSC will deliver data rates of 25 Megabits per second, instead of 250 kilobits, and a range of up to 1 km, instead of 10 meters. This basic difference makes it possible for DSRC to offer a much higher data transmission speed than RFID does. Because of its long read-range, DSRC must be able to operate in a condition of multiple overlapping communication zones – a condition that most RFID systems today can not meet. Furthermore, DSRC must also dynamically control such things as emitted power, channels and message priorities – things that current RFID systems cannot do. As mentioned earlier, the RFID technology discussed in this section is the next generation low-cost "smart" RFID system that is currently being developed at the Auto-ID Center (Sarma, 2003; Juels et al., 2003). The main features of this technology are the potential for very low cost transponders (under $0.10 each) (Sarma, 2001), 13.56 MHz and 915 MHz ISM bands in the US (permitting multiple reader-to-tag communication options), and a better attendance to security and privacy issues (Jeuls et al., 2003).

Table H3.2: Values of the criteria for each technology

Technology / Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Manual Toll Booth (MTB)(1)	long	10	10	2	4	4	10	3	No	4	Not Easy	4	Good	No	Yes	1
ANPR (2)	long	3	7	6	2	2	4	2	No	3	Easy	2	Good	No	Yes	3
DSRC (3)	long	3	5	8	2	3	5	2	No	3	Easy	2	Good	No	Yes	3
GPS (4)	long	8	3	4	3	2	4	3	No	1	Not Easy	3	V.Good	No	Yes	4
Infrared (IR) (5)	long	8	3	3	3	3	3	2	No	2	Not Easy	2	Good	No	Yes	3
RFID (6)	medium	3	2	3	1	1	3	1	No	1	Easy	1	V.Good	No	Yes	2

Table H3.3: Values of the indifference and preference threshold for selected criteria with and without sensitivity analysis

Criteria	Indifference Threshold	Preference Threshold	Indifference Threshold (Sensitivity Analysis)	Preference Threshold (Sensitivity Analysis)
2	1	2	2	7
3	1	2	2	6
4	1	2	0	1
5	0	1	0	1
6	0	1	2	6
7	1	2	2	6
8	1	2	1	7
10	0	1	0	1
12	0	1	0	1
16	0	1	0	1

The results from the upward and downward distillation procedures after implementing the algorithms in Tables H3.2 and H3.3 are shown in Figure H3.1. The final rankings of the different technologies after the distillation process are shown in Figure H3.1.

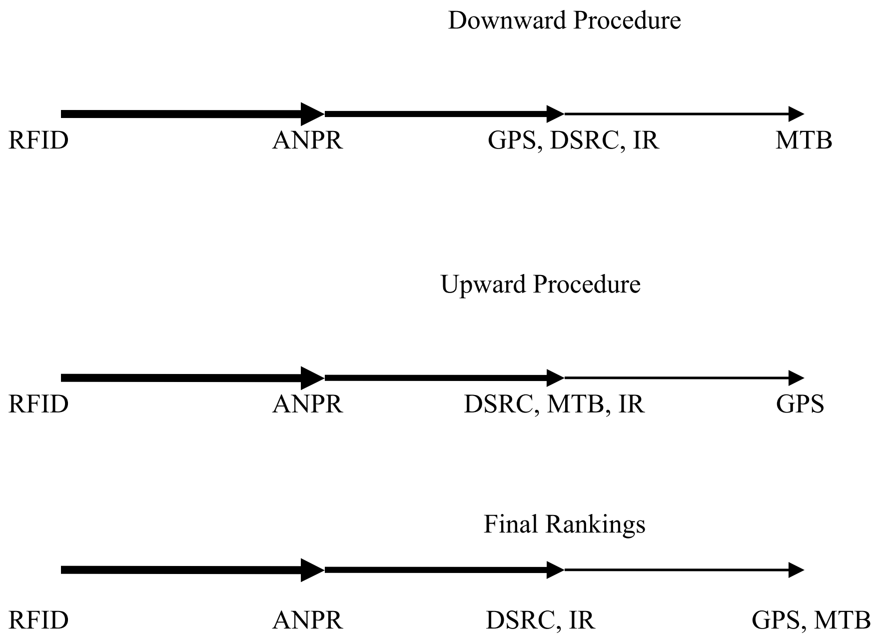

Figure H3.1: Outcome of the distillation procedure and the final ranking of CP technologies (Note: Link direction and line thickness indicate order of priority.)

From the above assumptions of preference and criteria values, and analysis we conclude that the best technology among the alternatives evaluated is the “smart” RFID technology. This result is corroborated by recent studies suggest that the next generation of enabling technology is wireless technology with RFIDs (Sarma et al, 2003 and Zuckerman, 2004). The next best technology is ANPR, which is ranked better than the GPS technology (as experienced in the PRoGReSS demonstration projects). It can also be observed that GPS performs poorly as compared to ANPR; however, all the technologies are at least as appropriate as Manual Toll booths. The results obtained here are consistent with the implementation experiences from PRoGReSS demonstration projects. Referring to Figure 4, it is evident that to choose between DSRC and Infrared a value judgment (regarding the relative importance of the criteria) is needed. However, the results obtained are not the final word on the ranking of technologies. Significant uncertainties may exist in the criterion values (Table H3.2). To account for this we performed a sensitivity analysis by considering the extreme thresholds for each criterion, as shown in Table H3.3. We then substitute singly all the extreme thresholds for the base thresholds (Table H3.3). This resulted in five new sets of values for the thresholds, in addition to the initial control set. Each of these six sets was processed through the four outranking systems (strong, weak, downward and upward), resulting in 23 new partial pre-orders. For brevity, we discuss only the conclusions of this analysis.

We observe that there is considerable stability in the rankings initially obtained, in all 23 scenarios considered.

- In all 23 scenarios, RFID technology remains the most preferred technology. The rankings of other technologies change, but there is a consistent pattern to the results.
- In 14 scenarios, MTB is ranked last while DSRC was ranked before MTB. This ranking is either reversed or there is a tie in all other scenarios.
- The IR technology is consistently ranked second in 17 of the scenarios. In a few of the scenarios this place is taken by ANPR.
- GPS is ranked either third or fourth in most of the scenarios; their relative position fluctuates considerably.
- There are 4 scenarios in which the options 2, 3, 4 and 5 are ranked second.

The consistency of these results gives us sufficient confidence on the ranking of technologies and further sensitivity analysis is not required. Other intermediate results were analyzed which confirmed these same observations. The analysis of the scenarios appears to clearly validate the results mentioned in Figure H3.1. However, one important caveat is that considerations external to those mentioned in Table H3.2 may modify some of the results obtained here. However, these criteria can be incorporated with the maturity of the decision-making process.

The above evaluation framework is semi-quantitative and requires input parameters such as indifference and preference thresholds for different technologies. However, in the event, such parameters are not available or the evaluation personnel cannot implement ELECTRE IV methods, an ad hoc approach can be used. On the basis of Porter et al.'s (2004) research, an ETC system for TxDOT's application of CBCP will require consideration of six features: roads to be priced, AVI technology to be used, metrics to be used for toll determination, toll types, toll collection, and level of enforcement. Note that the communication medium for enforcement and payment is related to the type of AVI technology that is implemented. For example, the communication medium for variable pricing with an entry-based charge could be a variable message sign at the entry point. The communication medium for distance-based charges is, implied by the AVI technology chosen. The distance-based metric will be pertinent for CBCP. However, the entry-based metric will be mentioned in this section, for sake of completeness and for contrast with the distance-based system. The six features can be configured in different ways as follows (Porter et al., 2004):

1. Roads to be priced
    - Roads within a predefined area
    - A single, specific road
    - Specific roads within an area
2. AVI technology
    - Inductive loop system
    - Optical license plate identification
    - Bar code
    - Active radio frequency (RF)/microwave system
    - Passive RF/microwave system
    - Surface acoustical wave (SAW) system
    - Dedicated short range communication (DSRC)
    - On-board unit (OBU) with or without GPS for mobile communication

3. Metrics for toll determination
   - Road-related metrics
     - Cordon Charge
     - Point charge
   - Vehicle-related metrics
     - Weight
     - Fuel economy
     - Emissions levels
     - Vehicle type (e.g., trucks, buses, and passenger cars)
4. Pricing fees
   - Fixed charge
   - Variable rates by level of traffic/congestion
   - Variable rates by time of day
   - Variable rates by area
   - Variable rates by road
5. Fee collection
   - Centralized: Drivers pay after road use. Data is sent to a central center where it is processed for fee calculation and bills are generated. Then, fee collection is carried out.
   - Hybrid: Drivers may pay before or after road use. Data on vehicles is collected and sent to a central processing center. Fees are computed and either deducted from the prepaid accounts or collected as part of fuel purchases. No billing and collection is necessary.
   - Decentralized: Drivers pay before road use. No data is sent to a central processing center, and no billing and collection is required.
6. Enforcement
   - Integrated: The enforcement is integrated into the ETC system in such a way that information generated as part of the system can be used for enforcement.
   - Separate: The enforcement system is another system in addition to the ETC system.

CBCP can be implemented in any of the three road-pricing scenarios, regardless of the other configuration of the other features. Also, CBCP can be applied using vehicle-related metrics for toll determination, regardless of the configurations of other features. Among the remaining features, the road-related metric is the major decision that will influence the design. Therefore, the road-related metric used to determine tolls must be decided first, because it will influence the other features of the system (Porter et al., 2004). The possible features for implementing CP project are given in Table H3.4, with comments on particular options. However, for implementing the CBCP the parameters related to point-based deployment (possibly based on a specific roadway feature, e.g. bridges) are most suitable. Table H3.4 has been modified from Porter et al. (2004). In Table H3.4, the point-based metric is contrasted with the cordon-based metric for toll determination. For each scenario, the implementing technology possibilities are examined for their applicability and any issues that may arise. Note that the interoperability issue will influence the choice of AVI technology or GPS.

Table H3.4: Recommendations for Possible Features of Selected CBCP Scenarios

Features	Cordon-based metric used for toll determination	Point-based metric used for toll determination
1) Roads priced	Applicable	Applicable
2) Vehicle-related metric used for toll determination	Applicable	Applicable
3) AVI technology		
OBU with GPS	Applicable. (Passive/read-only systems are sufficient. Pros and cons of these AVI technologies are listed in Table 1.)	Applicable with (1) the capability to transfer data (e.g., distance traveled and tolls) off the vehicle, and (2) a means to collect distance by geographic area or by specific road.
Inductive loop		Applicable with (1) a large investment for RF or DSRC capable readers installed at multiple locations on all roads within the system, (2) extensive networking, and (3) large amounts of computational power
Optical license plate identification		
Bar code		
Active RF		
Passive RF		
SAW		
DSRC*		
4) Pricing tolls		
Fixed charge	Applicable	Not applicable
Rates vary by congestion level	Applicable. Communication of congestion status and/or toll changes to OBUs and drivers need to take place at the specific entry points.	Not applicable, owing to the need to transfer information to a vehicle that may be anywhere in a specific area. Communication of congestion status and toll changes to OBUs and drivers would have to occur on all roads. However, it may be possible if OBUs can reliably collect the distance and time of travel and pass this information to a central processing center.
Rates vary by time of day		Applicable. Communication of toll changes to OBUs and drivers needs to occur
Rates vary by area		
Rates vary by road		
5) Toll collection		
Centralized (pay after road use; toll billing)	Applicable	Applicable
Hybrid (pay before or after road use; no toll billing)	Applicable	Applicable

Decentralized (pay before road use; no toll billing)	Applicable	Not applicable
6) Enforcement		
Integrated	Not applicable	Applicable if all drivers are required to participate. Data can be collected to identify those drivers not paying tolls.
Separate	Applicable	Applicable

* The Federal Communications Commission (FCC) recently allocated a co-primary spectrum 75 MHz in the 5.9 GHz band for transportation applications, referred to as Dedicated Short Range Communication (DSRC), between vehicles and electronic hardware on the roadside.

Appendix I1: Overview of Visual Interactive System for Transport Algorithm (VISTA)

VISTA is an innovative network-enabled framework that integrates spatio-temporal data and models for a wide range of transport applications: planning, engineering and operational (Ziliaskopoulos and Waller, 2000). The following information is derived from Ziliaskopoulos and Waller (2000). VISTA can be accessed via a cross-platform JAVA client or a web page. The client software allows performing all basic transportation GIS type operations such as zooming, displaying multiple layers, adding intersections, street segments, signal controls, ITS devices, etc. as well as running the modules, accessing the data warehouse and seeing some reporting (mostly graphical, such as 2-D animation and plots of measures of performance). The web page provides the same functionality; however, more emphasis is given in the detail customizable reporting, rather than the graphics.

The pioneering feature of VISTA is that it runs over the network on a cluster of Unix/Linux machines. It follows Sun Microsystems paradigm of the NETWORK COMPUTER. This enables accessing it from anywhere, anytime and from any machine without worrying about available computational power of the client machine to run sophisticated Dynamic Traffic Assignment, Control and Simulation models.

The mission of VISTA is to become the distributed warehouse for all data and models for traffic operators, engineers and transportation planners. All these users will be able to access the same consistent data, run models, make decisions (real-time, operational or planning) and produce reports that can be shared among all stakeholders of the transportation system.

The structure of VISTA is revolutionary. It uses the Internet not simply as an information dissemination medium but also as the means to access and run algorithms. Many of the traffic models and algorithms require an enormous amount of computing resources to run on any actual networks. In particular, Dynamic Traffic Assignment computes the path choices of all drivers on the network and simulates their spatio-temporal trajectory, while accounting for traffic signal transition, VMS strategies, ramp metering, tolls, detectors, etc. This is computationally daunting even for toy networks. VISTA can run very-large-scale networks, such as the Chicago 6 county-area network, in reasonable time, no matter where you run it from, because it always runs on the cluster of servers and workstations.

The data warehouse can be simultaneously accessed by many users. Each user logs on the system with his own authorization level and depending on that can see/modify data, run algorithms, create scenarios, run tests and produce reports. All modifications to the system must ultimately be approved by the VISTA Administrator. VISTA relies on the existence of the Internet that provides a cheap and ubiquitous medium of communication among spatially disperse users.

Framework Architecture

VISTA brings together data, models, users and applications into a seamless efficient, interwoven system. It is a CORBA compliant distributed system accessible over a network including the Internet. The client is machine independent (JAVA technology), user friendly and accessible based on various authorization levels. Data and models can be accessed by all users at different capacities, for retrieval, maintenance and analysis. CORBA is employed since application modules are written in a variety of languages (C, C++, FORTRAN, etc.) and may run on various Windows or UNIX platforms. Specifically, the system includes:

- A data warehouse module accessed over a network (Intranet/Internet)
- Existing and new transportation models and tools (planning, engineering, control, monitoring, evaluation and operational).
- User interfaces for the various stakeholders that enable access to the data and models from any computer hardware, at any location, at any time, by any user.
- The system is a CORBA compliant distributed system, allowing for CPU intensive models to be executed on many computers.
- Support capabilities for all relevant transportation applications.
- Functionality for interaction among users
- Some reporting capability
- Security features for many users accessing the same database at various authorization levels.
- Some basic administrative capabilities.

The overall structure of VISTA is outlined in Figure I1.1.

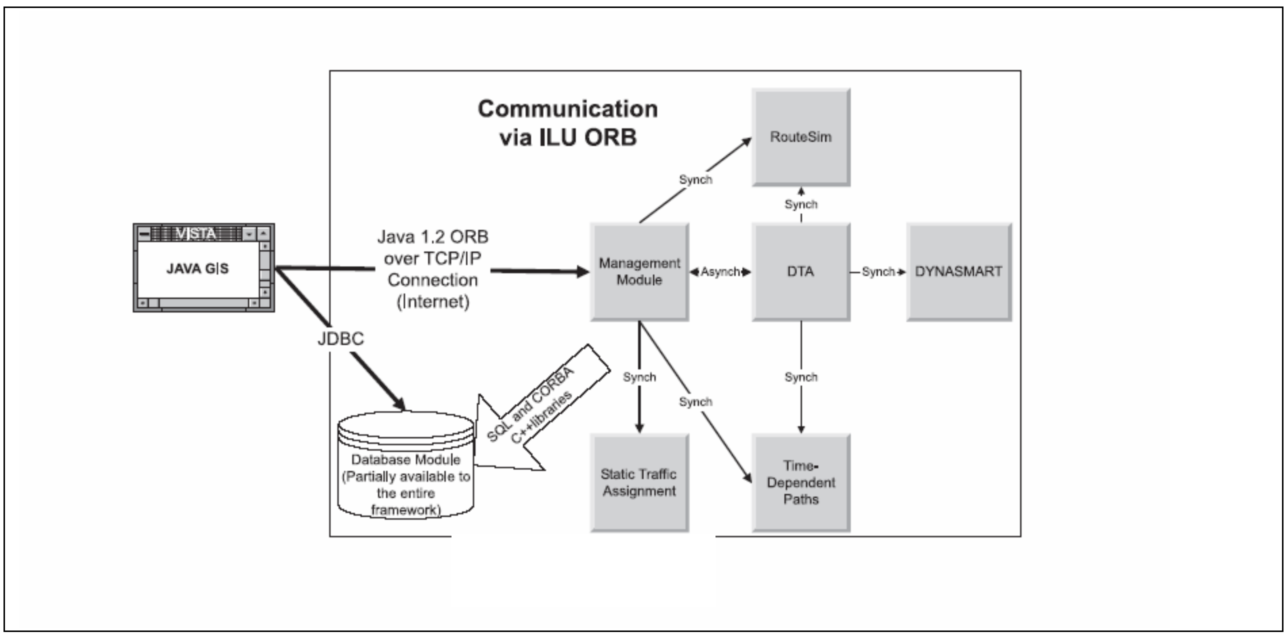

Figure I1.1: VISTA Structure (Ziliaskopoulos and Waller, 2000)

The user interface was written entirely in JAVA so that it can easily be used on multiple platforms and across the Internet. It communicates with the Management Module through the standard JAVA 1.2 Object Request Broker (ORB), allowing any user with a web browser to access the system by using the JAVA 1.2 plug-in. The interface works as a client exclusively, and communicates only with the Management and Database modules. The database module is based on a combination of the PostgreSQL database management system and specialized file handling routines. The specialized routines are implemented in order to store intermediate model data in an optimal manner. Such data include the travel costs as reported by the simulator within each iteration of the DTA algorithm. However, once the algorithm is complete, the cost data is transferred into the Structured Query Language (SQL) database in both desegregate and filtered aggregate form in order to support a unified reporting model. The original intermediate binary data can still be accessed through C/C++ and CORBA library functions. The database module can be accessed through CORBA, C/C++, Open Database Connectivity (ODBC), or JAVA Database Connectivity (JDBC) libraries. By implementing an abstraction over the database interfaces, the underlying modules can easily migrate to work with a variety of other relational database management systems. In addition, the networked nature of the VISTA framework also enables the parallelization of resource-intensive models. Some of the algorithms in VISTA can be migrated from serial to parallel implementations with minimal effort. This allows multiple processors to finish a model in a fraction of the time a single processor would require.

Model Structure

The primary modules in the VISTA framework include a traffic simulator (RouteSim), traditional (static) planning models, Dynamic Traffic Assignment (DTA) models, network routing algorithms, signal optimization models, ramp metering and incident management models. The interactions among models are coordinated by the central management module. Although each of these models may have different data type and structure requirements, the format for this data is kept uniform. The way in which the VISTA modules interact is represented in Figure A1. Each interaction is specified as either a synchronous or asynchronous invocation. Here, only the relevant models (management module, DTA, RouteSim and routing algorithms) are briefly described.

Management Module

The Management Module is the central component of the VISTA framework, and one of the only modules the user interface directly communicates with. It continuously runs on the server, handles incoming requests from remote interface modules, and executes the algorithm modules. A remote CORBA object can be described by its IDL file (Object Management Group, 1995).

When the Management Module first runs, it creates an HTML file, which contains the IOR string as an HTML parameter. This string uniquely identifies the Management Module as a CORBA object. By knowing this string, any CORBA enabled object present on the Internet has the ability to lookup and communicate with the Management object. Alternatively, a remote module could contact various system modules by accessing the CORBA naming service available on the central server.

Routesim

RouteSim is a mesoscopic simulator based on an extension of Daganzo's (1994) cell transmission model introduced by Ziliaskopoulos and Lee (1996). RouteSim is one of the fundamental modules, since it is used for simulation, dynamic traffic assignment and evaluation. The main enhancements over the basic cell transmission model are (i) the concept of adjustable size cells that improves the flexibility, accuracy and computational requirements of the model, and (ii) a modeling approach to represent signalized intersections. The basic cell transmission model along with the enhancements yields a model that can simulate integrated freeway/surface street networks with varying degree of detail. RouteSim requires as inputs network geometry and path flow data. The path flow data can be generated from time-dependent or static origin-destination matrices or input directly by the user. RouteSim assigns every generated vehicle to a path, similar to the DYNASMART model introduced by Mahmassani et al. (1993). An advantage of RouteSim is that the simulation step and the representational detail are adjustable to the geometry of the network. Lengthy freeway segments that do not need to be modeled in detail are simulated as aggregate long cells and their state is updated infrequently, e.g. a two-mile freeway segment without on- and off- ramps could be modeled as a single cell and be updated every two minutes. On the other hand, close to intersections or problematic points where the evolution of queues, spatio-temporal traffic dynamics and signalization phases need to be captured in detail, the simulation step can be as small as two seconds. Simulation steps of this magnitude allow detail representation of signalized intersections- i.e., signal control strategies, phasing, start-up/lost times and gap acceptance behavior. In addition, while detail data (e.g., geometry, timing plans, turning movements) are required for accurately simulating a network with signalized intersections, RouteSim will run even if no such data are provided, by assuming (and prompting the user), geometry, control and traffic data.

Dynamic Traffic Assignment (DTA)

The DTA model used in this project is a departure time based version of simulation-based user equilibrium (UE) DTA approach using RouteSim to propagate traffic and satisfy capacity constraints. The DTA model use the geometry, control and demand data inputs; the demand tables need to be departure time based. The simulation-based DTA model accesses the simulator (RouteSim), time-dependent least time and cost path modules, as well as various other modules. Since this system works in an iterative scheme, the computational time of sub-modules becomes very important. The DTA model is the most time consuming model, but many of these modules have operations that can be run in parallel. For instance, the time-dependent shortest path algorithms have the ability to be distributed over multiple processors (Ziliaskopoulos et al., 1998). Since VISTA is based on the CORBA specification, it can handle the communication and invocation of these modules on separate processors.

Routing Algorithms

Various routing algorithms can be invoked through VISTA. The relevant one is the time-dependent shortest path algorithm. Implementation details can be found in Ziliaskopoulos and Mahmassani (1994). The routing algorithm requires as input the link travel times and/or costs and the network topology; it has the capability to account for intersection movement delays. The output is typically a tree, rooted at the destination.

Required VISTA Formats of Four Essential Tables

The four essential tables are Nodes, Links, Linkdetails and Demand.

Nodes

The nodes table contains a record for each node in the network. Nodes are unique.

Table I1.1: VISTA Format for Table Nodes

Field	Data Type	Description
Id	integer	A unique identifier per node. These are positive integer values.
type	integer	This field should be 1 for a mesoscopic node, 2 for a microscopic node, or 100 for a centroid.
x	double precision	This field is the x-coordinate of the node.
y	double precision	This field is the y-coordinate of the node.

Links
This table contains a record for each unidirectional link in the network. Links are unique by id. Each entry in the links table should have a matching entry in the linkdetails table.

Table I1.2: VISTA Format for Table Links

Field	Data Type	Description
id	integer	A unique identifier per link. This must be a positive value.
type	integer	1 for a mesoscopic link, 2 for a microscopic link or 100 for a centroid connector link.
lanes	integer	The number of lanes on a link. This is must be a positive value.
points	path	The actual geometry of a link. This cannot be null.

Linkdetails
This table contains a record for each link in the network. Links are unique by id. Every entry in links should have a corresponding entry in the links table.

Table I1.3: VISTA Format for Table Linkdetails

Field	Data Type	Description
id	integer	A unique identifier per link. This must be a positive value.
type	integer	1 for a mesoscopic link, 2 for a microscopic link or 100 for a centroid connector link.
lanes	integer	The number of lanes on a link. This is must be a positive value.

`origin`	integer	The origin node id of a link. This is a reference to node id.
`destination`	integer	The destination node id of a link. This is a reference to node id.
`length`	real	The length of a link in feet.
`speed`	real	The speed limit of a link in miles per minute.
`capacity`	real	The saturation flow of a link in vehicles per hour. This field is optional.

Demand
This table contains a record for each vehicle that will be routed through the network. The contents of the demand table is generated by the demand profiler. Vehicle entries in the table are unique by id.

Table I1.4: VISTA Format for Table Demand

`Field`	Data Type	Description
`id`	integer	A unique identifier per vehicle. These are positive integer values.
`type`	integer	1 for a passenger vehicle or 2 for a truck. This will change in future versions of VISTA.
`origin`	integer	The node id at which a vehicle originates. This is a reference to node id.
`dest`	integer	The node id at which a vehicle finishes. This is a reference to node id.
`ast`	integer	The assignment interval a vehicle falls into, from zero up to n-1 of n assignment intervals.
`vehs`	integer	This field should always be 1. It will be removed from future versions of VISTA.
`dtime`	integer	The departure time of a vehicle. This is the number of seconds after the beginning of simulation at which the vehicle enters the network. This will change in future versions of VISTA.

Appendix I2: DTA Solution Algorithm Implementation Details

Background

DTA models are typically classified into two broad categories: analytical models and simulation-based heuristic models (Ziliaskopoulos et al., 2004). Extensive work has been reported for both types of approaches, and an overview of this literature can be found in Peeta (1994) and Mahmassani et al. (1993). Analytical methods have advanced greatly since the pioneering work of Merchant and Nemhauser (1978a,b) and Carey (1986, 1987, 1992). Efforts in this area include mathematical programming approaches by Janson (1992) and Ziliaskopoulos et al. (1998), optimal control theory based formulations by Friesz et al. (1989), and variational inequality approaches introduced by Friesz et al. (1993), Smith (1993), Wie et al. (1995), Boyce et al. (1996), and Lee (1996).

Most analytical formulations are extensions of their equivalent static formulations and seem to have two main disadvantages: (i) they cannot adequately capture all realities of street networks due to simplifications, and (ii) they tend to be intractable for realistically sized networks. Heuristic approaches, especially those that are simulation-based, overcome these disadvantages, but fail to guarantee optimality and often even convergence. Moreover, unlike closed-form analytical formulations, they lack the potential to obtain insights into the problem. While further research into these analytical models is vital to the understanding and future applicability of DTA, the simulation-based models appear to be the only ones currently applicable to actual large networks.

Currently, there are two main simulation-based approaches in the literature: DYNASMART-X (Mahmassani et al., 1993) and DYNAMIT (Ben-Akiva et al., 1997). The DTA model in VISTA is based on DYNASMART-X. The main difference between these two models is the replacement of the traffic simulator DYNASMART (Mahmassani et al., 1993) with RouteSim (Ziliaskopoulos and Lee, 1996). RouteSim is a traffic simulator based on the Cell Transmission Model (Daganzo 1994, 1995). In addition, the path assignment module and time-dependent shortest path module were re-engineered into an efficient module that can handle large data sets, intersection movement delays and link travel times. Finally, database support was added to handle critical data communication issues involving the link flows, travel times, and path storage, based on a key/data pairing database system.

The DTA system can be broken into three general modules: the traffic flow simulator, the time-dependent shortest path algorithm, and the path assignment module. Each module has singularities that must be addressed when applying the system on large-scale realistic networks.

The Traffic Simulator RouteSim

RouteSim (Ziliaskopoulos and Lee, 1996) is a path-based simulator that propagates traffic according to the Cell Transmission Model (Daganzo 1994, 1995). In a preprocessing step, it divides the network links into a number of cells based on their length and free-flow speed and transmits vehicles between cells according to the cell's density, the downstream cell's density and jam density, and the saturation flow rate. Since this involves only simple comparisons and not complex floating-point calculations, RouteSim can handle networks of thousands of links while maintaining acceptable CPU time and memory requirements. In addition, the simulator has been designed to update the vehicle movements at varying time intervals, depending on how frequently the queue evolution needs to be monitored. Close to intersections, incidents, construction zones and other problematic points, the simulator updates the queues every two seconds; for long uniform freeway segments, it updates at multiples of that time period, up to twenty seconds. This results in enormous CPU savings without substantially sacrificing accuracy of computations.

Another issue encountered in simulating traffic for assignment applications is the calculation of the link travel times. If this calculation is CPU expensive, it can be the computational bottleneck for the overall approach; the calculation of travel time is similar to an efficient approach proposed by Lawson et al. (1996). As the simulation progresses, it begins by recording the cumulative flow into and out of each link. Furthermore, this method must also be able to calculate movement delays. Therefore, when a vehicle enters a link, its next desired link is examined; the vehicle is then recorded as an inflow for the link-movement combination it intends to perform. When a vehicle departs from a link, it is recorded as an outflow for the intersection movement performed. This effectively creates two vectors: INFLOW and OUTFLOW for each link-movement combination indexed over time. In a post-processing stage, these cumulative flows are examined to calculate the travel time for every link and movement performed.

This approach allows the simulation to continue indefinitely, since no output data is stored in memory. As the simulator iteratively progresses, it stores density and flow data into a file, without maintaining any additional past information. In addition, if the flow file grows too large, it can be erased or aggregated without affecting future simulation steps.

Path Assignment and Data Handling

The path assignment and time-dependent shortest path (TDSP) modules were combined into a single software entity, which eliminates the need to record the labels generated by the TDSP algorithm between successive iterations. Furthermore, since the TDSP and assignment modules are both able to execute by destination, only the labels for a single-destination must be stored in memory at any time.

The assignment module is responsible for handling most of the complex data manipulations. It reads the TDSP labels, the OD demand information, and maintains a set of used paths for each OD pair. This set of paths, however, could become prohibitively large as the network size increases, and it may not be possible to cache all paths in the memory. To deal with this problem, a data/key pairing database system is employed that is capable of handling binary-tree and hashed data storage and retrieval as well as data caching. One such system is BerkeleyDP (Olson et al., 1999), which is the database adopted in this implementation.

Three key data elements are stored in the database, in every iteration: the link flows, the travel times, and the path sets. The flows and travel times are stored as typical vectors indexed over time. This provides a convenient structure for computing the travel times, since this calculation is performed on a link basis rather than on a time interval basis; thus, efficient database searches can be used to retrieve only information by link instead of by time. The path set is stored as a dynamic vector with a key containing the destination, assignment time and iteration. Each record consists of the optimal path calculated during the iteration for each origin to that destination, in the specified time period. Since an efficient Binary-Tree search is performed to store and retrieve this information, this allows all computations within the TDSP and assignment modules to only require data for the needed destination, thus consuming considerably less memory.

Accounting for Intersection Turning Movements, Entry and Exit Delay

An approach typically used to compute shortest paths with turning movements is to expand each intersection into a more detailed sub-network (Ziliaskopoulos and Mahmassani, 1996). In the sub-network, each incoming or outgoing approach in the original network is represented by a node and each movement is represented by an arc connecting these nodes. With such an expanded network, movement delays at intersections can be modeled by the travel times on the arcs, and any shortest path algorithm can be used to handle the problem. The disadvantage with this approach is that the size of the network after expansion is usually much larger than the size of the original network, thus causing a significant increase in memory requirements and computational time.

The time-dependent shortest path algorithm used with the simulator takes into consideration optional movement delays at intersections and entry/exit delays at origin/destinations. This algorithm is an important modification to the original one because it can capture the impact of turning movement delays on the routing decision of travelers. Such impact is evident on real street networks, and the ability to account for it addresses the underlying theme of implementing DTA on such networks.

Method of Successive Averages (MSA) for Dynamic Traffic Assignment

The MSA algorithm for DTA is described as follows (Peeta and Mahmassani, 1995):

Step 1. Set the iteration counter c=0. Assign the given time-dependent origin-destination demands r_{ij}^{τ} to the free flow paths; thus, obtaining the initial assignments $p_{ijk}^{\tau,c}$.

Step 2. Perform simulation to obtain time-dependent link travel times.

Step 3. Compute time-dependent least cost paths k^*

Step 4. Perform all-or-nothing assignment by assigning OD demands r_{ij}^{τ} to the corresponding time-dependent least cost path. This gives the auxiliary number of vehicles on paths $y_{ijk^*}^{\tau,c}$.

Step 5. Path update is done by checking if the auxiliary paths are pre-existing paths, and including them if they are not. Thus, this method does not require a priori complete path enumeration.

Step 6. Perform the Method of Successive Averages (MSA). The path assignment for the next iteration, $p_{ijk}^{\tau,c+1}$, are obtained by a convex combination of the current path assignments $p_{ijk}^{\tau,c}$ and the auxiliary path assignments $y_{ijk^*}^{\tau,c}$:

$$p_{ijk}^{\tau,c+1} = \left(\frac{1}{c+1}\right) y_{ijk^*}^{\tau,c} + \left(1 - \frac{1}{c+1}\right) p_{ijk}^{\tau,c}.$$

Step 7. The convergence criterion is based on the difference in the number of vehicles assigned to various paths over successive iterations. The path assignments for the next iteration $p_{ijk}^{\tau,c+1}$ are compared with the current path assignments $p_{ijk}^{\tau,c}$:

$$\left| p_{ijk}^{\tau,c+1} - p_{ijk}^{\tau,c} \right| \leq \varepsilon \text{ , } \forall i, j, k, \tau$$

The number of cases $N(\varepsilon)$ in which their absolute difference is greater than a value ε is recorded.

Step 8.

(i) If $N(\varepsilon) \leq \Omega$, convergence is assumed and terminate the algorithm. Ω is a pre-set upper bound on the number of violations of the equation in Step 7. The output is the path assignments $p_{ijk}^{\tau,c+1}$ as the solution to the user-optimal DTA problem.

(ii) If $N(\varepsilon) > \Omega$, the convergence criterion is not satisfied. Update c=c+1. Go to Step 2 with the new current path assignments $p_{ijk}^{\tau,c+1}$.

Where

r_{ij}^{τ} = travel demand departing from origin *i*, at time τ, to destination *j*

$p_{ijk}^{\tau,c}$ = number of vehicles departing from origin *i* at time τ to destination *j* assigned to path *k* when iteration counter at *c*

$y_{ijk}^{\tau,c}$ = auxiliary number of vehicles departing from origin *i* at time τ to destination *j* assigned to path *k* when iteration counter at *c*

Appendix I3: Time Dependent Shortest Path (TDSP) and Time Dependent Least Cost Path (TDLCP) Algorithms

The following TDSP algorithm is taken from Ziliaskopoulos and Mahmassani (1994).

Let $G = (V,E)$ be a V node finite directed graph with E directed edges connecting the nodes. Let $d_{ij}(t)$ be the non-negative time required to travel from Node i to Node j when departure time from Node i is t; $d_{ij}(t)$ is a real-valued function defined for every $t \in S$, where $S = \{t_0, t_0 + \delta, t_0 + 2\delta, ..., t_0 + M\delta\}$, t_0 is the earliest possible departure time from any origin node in the network, δ is a small time interval during which some perceptible change in traffic conditions may occur, and M is a large integer number such that the interval from t_0 to $t_0 + M\delta$ is the period of interest (e.g. AM peak).

It is assumed that $d_{ij}(t)$ for $t > t_0 + M\delta$ is constant and equal to $d_{ij}(t_0 + M\delta)$. This is a reasonable assumption for urban transportation networks where, after the peak hour, somewhat stable travel times can be assumed. Nevertheless, it is not a restrictive assumption because M is user defined and can always be increased to include periods with variable travel times on some arcs. It is also assumed that $d_{ij}(\tau) = d_{ij}(t_0 + k\delta)$ for every τ in the interval $t_0 + k\delta < \tau < t_0 + (k+1)\delta$. This is not a restrictive assumption, considering that by definition δ is very small. Node N denotes the destination node of interest in the network. The algorithm calculates the time-dependent shortest paths from every node i in the network and at every time step t to the destination node N.

At each step of the computation, denote by $\lambda_i(t)$ the total travel time of the current shortest path from node i to node N at time t. Let $\Lambda_i = [\lambda_i(t_0), \lambda_i(t_0 + \delta), \ldots, \lambda_i(t_0 + \mathrm{M}\delta)]$ be an M-vector label that contains all the labels $\lambda_i(t)$ for every time step $t \in S$ for Node i. Every finite label $\lambda_i(t)$ from Node i to Node N is identified by the ordered set of nodes $P_i = \{i=n_1, n_2, \ldots, n_m=N\}$.

Time-Dependent Shortest Path (TDSP) Algorithm

Step 1. Create the Scan Eligible (SE) list and initialize it by inserting into it the destination node N. Initialize the label vectors at the following values: $\Lambda_N = (0, 0, \ldots, 0)$ and $\Lambda_i = (+\mathrm{inf}, +\mathrm{inf}, \ldots, +\mathrm{inf})$ for $i = 1, 2, \ldots, N\text{-}1$.

Step 2. Select the first node i from the SE list, name it "Current Node," and delete it from the list. If the SE list is empty, go to Step 4. Scan the current node i according to the following relation:

$$\lambda_j(t) = \min\{ \lambda_j(t), d_{ji}(t) + \lambda_i(t + d_{ji}(t))\} \quad \forall j \in \Gamma^{-1}\{i\}, t \in S$$

by examining each node j, $j \in \Gamma^{-1}\{i\}$. Specifically, for every time step $t \in S$, check whether $\lambda_j(t)$ is greater than $d_{ji}(t) + \lambda_i(t + d_{ji}(t))$. If it is, replace $\lambda_j(t)$ in the label vector Λ_j at position i with the new value. If at least one of the M labels of Node j has been improved, insert Node j in the SE list. The details of the structure of the SE list and the associated operations of creation, insertion, and deletion are referred to Ziliaskopoulos and Mahmassani (1994).

Step 3. Repeat Step 2.

Step 4. Terminate the algorithm. The M-dimensional vectors Λ_i for every node i in the network contain the travel times of the time-dependent shortest paths from every node i to the destination node N for each time step $t \in S$.

Time-Dependent Least Cost Path (TDLCP) Algorithm

The TDLCP algorithm is based on the TDSP. The following notations are added to the TDSP notations.

Let $p_{ij}(t)$ be the non-negative penalty time from nodes i to j when departure time from node i is t; $p_{ij}(t)$ is obtained by dividing toll on link (i,j) at time t by the value of travel time (VOTT) for every $t \in S$. It is assumed that $p_{ij}(t)$ for $t > t_0 + M\delta$ is constant and equal to $p_{ij}(t_0 + M\delta)$, and $p_{ij}(\tau) = p_{ij}(t_0 + k\delta)$ for every τ in the interval $t_0 + k\delta < \tau < t_0 + (k+1)\delta$. Let $\omega_i(t)$ be the total travel time of the current least cost path from node i to node N at time t. Let $\Omega_i = [\omega_i(t_0), \omega_i(t_0+\delta),\ldots, \omega_i(t_0+ \mathrm{M}\delta)]$ be an M-vector label that contains all the labels $\omega_i(t)$ for every time step $t \in S$ for node i. $\lambda_i(t)$ is redefined as the total generalized cost of the current least cost path from node i to node N at time t. The TDLCP algorithm is very similar to the TDSP algorithm, and is shown below.

TDLCP Algorithm

Step 1. Create the Scan Eligible (SE) list and initialize it by inserting into it the destination node N. Initialize the label vectors at the following values: $\Lambda_N = (0, 0, \ldots, 0)$; $\Omega_N = (0, 0, \ldots, 0)$; $\Lambda_i =$ (+inf, +inf, …, +inf) for $i = 1, 2, \ldots, N$-1; and $\Omega_i =$ (+inf, +inf, …, +inf) for $i = 1, 2, \ldots, N$-1.

Step 2. Select the first node i from the SE list, name it "Current Node," and delete it from the list. If the SE list is empty, go to Step 4. Scan the current node i according to the following relation:

$$\lambda_j(t) = \min\{\lambda_j(t), d_{ji}(t)+ p_{ji}(t) + \lambda_i(t+ d_{ji}(t))\} \quad \forall j \in \Gamma^{-1}\{i\}, t \in S$$

by examining each node j, $j \in \Gamma^{-1}\{i\}$. Specifically, for every time step $t \in S$, check whether $\lambda_j(t)$ is greater than $d_{ji}(t) + p_{ji}(t) + \lambda_i(t+ d_{ji}(t))$. If it is, replace $\lambda_j(t)$ in the label vector Λ_j at position t with the new value, and replace $\omega_j(t)$ in the label vector Ω_j at position t with the value $d_{ji}(t) + \omega_i(t)$. If at least one of the M labels of Node j has been improved, insert Node j in the SE list. The details of the structure of the SE list and the associated operations of creation, insertion, and deletion are referred to Ziliaskopoulos and Mahmassani (1994).

Step 3. Repeat Step 2.

Step 4. Terminate the algorithm. The M-dimensional vectors Λ_i for every node i in the network contain the generalized cost of the time-dependent least cost paths from every node i to the destination node N for each time step $t \in S$. The M-dimensional vectors Ω_i for every node i in the network contain the travel times of the time-dependent least cost paths from every node i to the destination node N for each time step $t \in S$.

Appendix I4: Method for Travel Demand Smoothing across Times of Day

Due to the absence of information regarding how travel demand (essentially trip departures) evolves over time, we distribute the demand using a nonlinear programming model. While we cannot determine how realistic the results (because there is insufficient time-dependent travel demand data available for robust calibration), we can ensure that the estimates of total trip-making within each general time of day are met. The proposed optimization model minimizes the summation of "demand differences" between two successive time periods with the conservation of total demand in each TOD. The formulation is described as follows:

Formulation

Sets

$j \in TOD = \{1,2,...,5\}$ = set of time-of-day

$i \in T = \{t_1, t_2, \ldots, t_N\}$ = set of time slices over the entire day (e.g., 288 5-minute time slices, so that $N = 288$) where N is the size (or length) of set T

T_j= set of time slices during the j^{th} TOD

Parameters

d_j = total travel demand during the j^{th} TOD

Variables

x_i = travel demand during the i^{th} time slice

Objective

$$\min_x f(x) = \sum_{i \in T} (x_i - x_{i-1})^2$$

Constraints

$$\sum_{i \in T_j} x_i = d_j \ ; \ \ \forall j \in TOD$$

$$x_i \geq 0 \ ; \forall i \in T$$

Solution Methodology

This nonlinear program minimizes a quadratic function subject to all linear constraints; hence, it is a quadratic programming (QP) model. We explored two available methods to solve this QP model: Frank-Wolfe (FW) algorithm and GAMS/MINOS. In both methods, we can specify the stopping criterion parameters. For FW, the stopping criterion is defined as:

$$\frac{f(x_k) - f(x_{k+1})}{|f(x_{k+1})|} \le err\_FW$$

For GAMS/MINOS, the stopping criterion is defined as the optimality gap is within the parameter *optcr*. Here, we only use a default value of *optcr*.

After, solving the QP model, travel demand during each time slice of five minutes is uniformly distributed over 50 time steps, where each time step is six seconds. Normally, the demand value from the QP model for each time step is not an integer value. The demand value is rounded down, and the fraction value is regarded as a probability of adding one more demand. Specifically, generate a random number between zero and one, if the random number is less than or equal to the probability, add one to the demand value. For example, a demand value of 0.65 is equal to 0 trip plus 65 percent chance of adding one more trip. Suppose the random number generator yields 0.70; then we do not add one more trip because 0.70 is greater than the probability of 0.65. If the random number is 0.55, one more trip is added. In the following illustrative example, the computational times versus the solution quality of the two methods are compared.

Illustrative Example

For DTA simulation, a five-minute time slice is considered reasonable as this is also the typical "assignment length" (the length of time where drivers' route choice options will not change). In other words, during this assignment length, all drivers will see similar route choice options. Thus, in this example we employ a time slice of five minutes. Suppose that we are given the total demands in each TOD for a single origin-destination pair as shown in Table I4.1.

Table I4.1: Total Travel Demands in Five TODs

Time Interval (*j*)	TOD	Number of 5-minute time slices	Total Demand per TOD (#trips)
1	6:00 AM – 9:00 AM	36	10,000
2	9:00 AM – 3:30 PM	78	2,000
3	3:30 PM – 7:00 PM	42	12,000
4	7:00 PM – 9:00 PM	24	3,000
5	9:00 PM – 6:00 AM	108	1,000

Using GAMS/MINOS to solve this QP model, the computational time is 0.210 cpu seconds on a ME HPC machine (a Dell Precision 530 Workstations with dual 1.8 GHz Xeon processors and 1 GB of RAM, running under SuSE Linux 9.0). Note that using GAMS, we cannot capture the total computational time including file input and output. Thus, 0.210 cpu seconds are only the time for the solver MINOS to solve the problem, and this could significantly be increased when accounting for file input and output. The resulting demand distribution is shown in Figure I4.1. Using the Frank-Wolfe algorithm with an err_FW value of 0.001, the computational time is 0.076 seconds on the same machine; the result is shown in Figure I4.2. Apparently, the Frank-Wolfe algorithm performs much better in terms of the computational time (about 3 times faster), but the solution quality is compromised: the resulting graph is less smooth than that from

GAMS/MINOS. Next, using Frank-Wolfe algorithm with the err_FW of 0.0001, the solution quality is a bit improved, but the computational time gets much worse, as shown in Figure I4.3.

The solution quality of the Frank-Wolfe algorithm with the err_FW of 0.001 appears acceptable with the significantly improved computational time. We proceed with this method. For 1 million OD pairs, the Frank-Wolfe algorithm with the err_FW of 0.001 will take 21.11 hours on ME HPC machine, whereas the GAMS/MINOS will take 58.33 hours on the same machine.

We now have two viable methods for smoothing the travel demand across times of day. The advantage of the Frank-Wolfe algorithm is its significantly shorter total computational time, but it yields a lower solution quality. The GAMS/MINOS option yields better solution quality, but provides only the CPU time rather than the total computational time. For 1 million OD pairs, using Frank-Wolfe algorithm, we can predetermine the total computational time; with GAMS/MINOS, there remains unknown time for file input and output that could dominate in the total computational time.

There is a possible improvement to the Frank-Wolfe code, via incorporating a better line search method. Currently, we use the golden section method, which is less efficient than the bisection method for this QP model. Since the first derivative of the objective function is just a linear equation and easy to calculate, the bisection method that requires the first derivative information will surely help improve the total computational time.

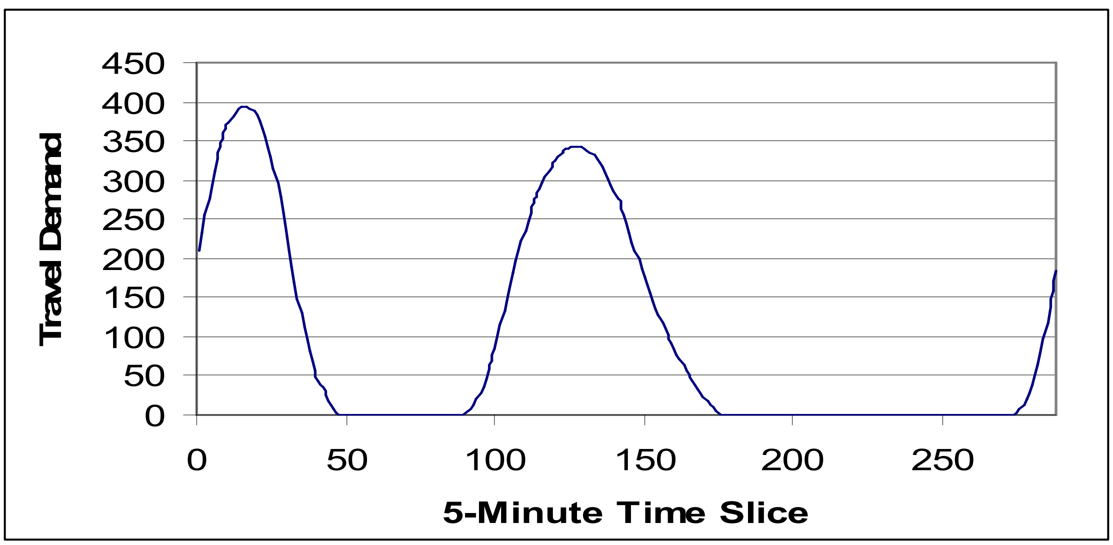

Figure I4.1: Time-Dependent OD Trips by GAMS/MINOS

(210 milli seconds on ME HPC machine)

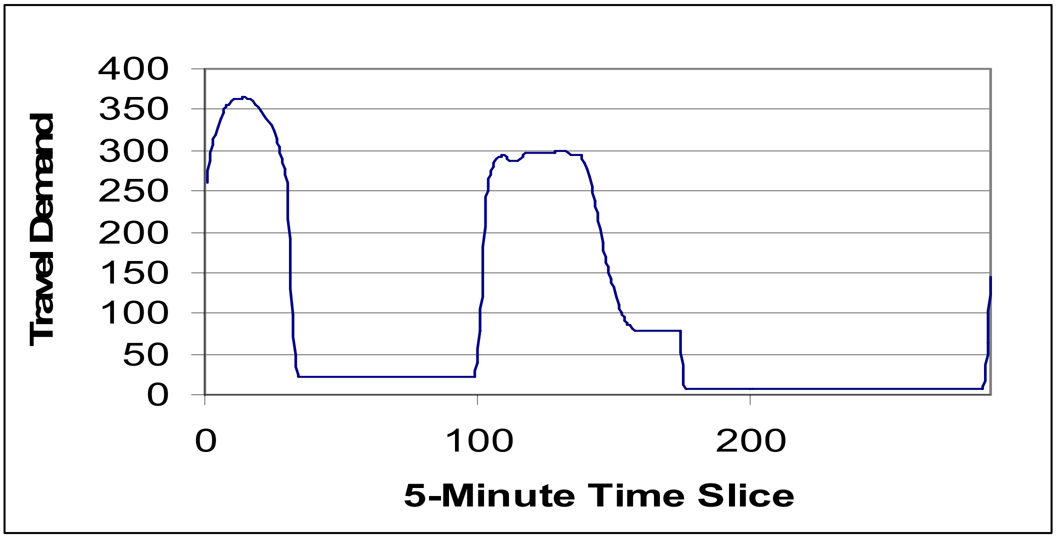

Figure I4.2: Time-Dependent OD Trips by Frank-Wolfe Algorithm

(err_FW = 0.001, 76 milli seconds on ME HPC machine)

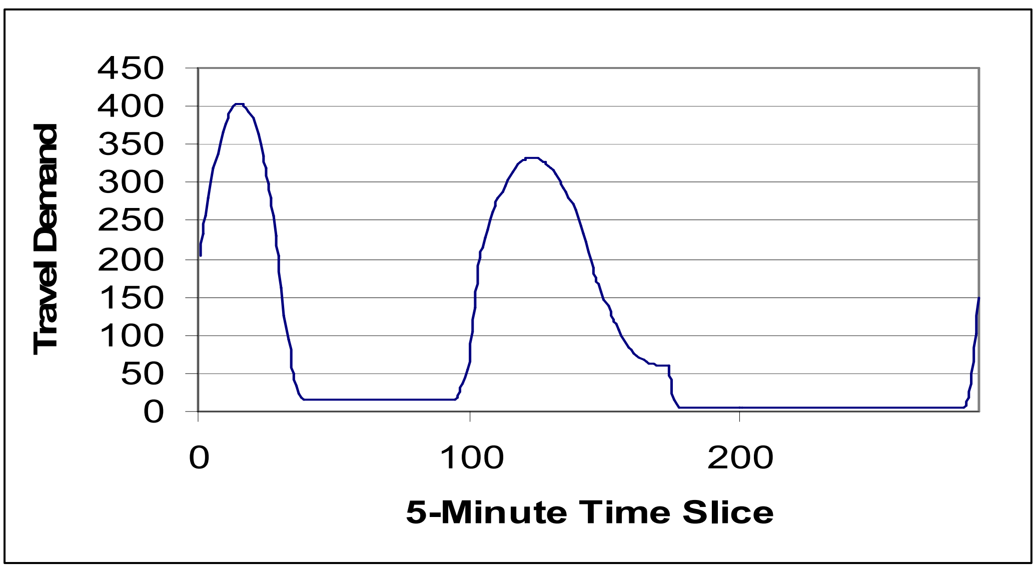

Figure I4.3: Time-Dependent OD Trips by Frank-Wolfe Algorithm

(err_FW = 0.0001, 595 milli seconds on ME HPC machine)

Appendix I5: Dynamic Marginal Cost Pricing

Literature Review

The literature on the dynamic congestion pricing is very limited. Joksimovic et al. (2005) formulated the second-best toll design problem in the dynamic traffic network as a bi-level optimization problem, considering elastic demand. They only showed a small hypothetical network and solved it by complete enumeration. Their DTA scheme is an extension of the static traffic assignment. Wie and Tobin (1998) proposed two dynamic congestion pricing models based on first-best marginal cost pricing. Their DTA scheme employs a link performance function to estimate link travel time. However, they did not show any illustrative example. The DTA models in both papers lack realistic traffic conditions, and they cannot capture traffic interactions across adjacent links. Mahmassani et al. (2004) proposed an efficient approximation algorithm for finding bi-criterion time-dependent efficient paths in large-scale traffic networks. Their algorithm can be used in conjunction with dynamic traffic assignment applications to networks with variable toll pricing and heterogeneous users.

This study is the first to propose a heuristic method for dynamic MCP on a subset of a major network (i.e., DFW's network, with only freeways being tolled). VISTA's DTA scheme is based on a theoretical model of traffic flow: Daganzo's (1994) cell transmission model. This model accounts for realities of traffic, like link capacities and queue spillbacks. Thus, it overcomes the weakness of using link performance functions, as typical in the literature. However, this study is limited to only route choice evaluation and homogeneous users, and does not allow elastic demand, destination, mode and departure time shifts. Thus, it cannot simulate the most significant behavioral impacts that one may expect under a pricing policy. Nevertheless, this study provides insight into the problem by accounting for traffic dynamics on a very large-scale network.

Time-Dependent Link Marginal Congestion Cost

When a vehicle enters a transportation network, it imposes two types of costs: the average cost experienced by the vehicle and a marginal congestion cost (experienced essentially by those following the new vehicle, under very slightly reduced speeds). (Liu and McDonald, 1999) In this study, we consider an heuristic (i.e., an approximation) for calculating the marginal congestion costs on tolled links. The assumption is that a vehicle entering a tolled link imposes marginal congestion costs only on all following vehicles using this same link. Thus, we assume that it does not impact vehicles using other, upstream (or downstream) links. The time-dependent link toll is the product of the time-dependent link marginal congestion cost (in seconds) and the value of travel time (VOTT, in $ per second).

Peeta and Mahmassani (1995) proposed the following computation of a link's approximate time-dependent marginal cost, t^{ta}, in terms of travel time (for all time periods *t* and links *a*):

$$t^{ta} = T^{ta}(x) + x^{ta}\frac{\partial T^{ta}(x)}{\partial x^{ta}}$$

where $T^{ta}(x)$ represents the travel time experienced by another vehicle entering link a at time t, x is the vector of time-dependent vehicle counts on all links (x^{ta}, $\forall t, a$), and dT/dx equal the link's marginal congestion cost (in seconds).

The spatial interactions and n^{th} order temporal interactions (global marginals) are ignored in this computation. These effects may not be significant compared to the direct effect on link a at time t, $\frac{\partial T^{ta}(x)}{\partial x^{ta}}$ (i.e. local marginals). Under such conditions, the solutions obtained using the global marginals and the local marginals will be relatively close. However, if the interactions are significant, the solution obtained using the local marginals may deviate from that obtained using the global marginals.

$T^{ta}(x)$ and x^{ta} are obtained directly from simulation. Figure I5.1 illustrates the approach used for the computation of the derivative $\frac{\partial T^{ta}(x)}{\partial x^{ta}}$. The approach used here assumes that the time-dependence of the derivative is due to "time-varying" link performance functions. This means the performance curve in Figure I5.1 for link a at time t depends on the traffic flow conditions on the link at that time. This time-dependence is very significant; a link's travel time can differ significantly the same number of vehicles at two different times depending on the fraction of vehicles that are queued. A link's link performance curve changes somewhat gradually over time. If the time interval between successive evaluations of dT/dx derivatives (marginals) is small, it appears reasonable to assume that three consecutive points in time are on the same link performance curve, as illustrated in Figure I5.1. A quadratic fit using the three points results in the time-varying link performance curve at time t and the slope of this curve at time t gives $\frac{\partial T^{ta}(x)}{\partial x^{ta}}$, as indicated in the figure. The following is an illustrative example.

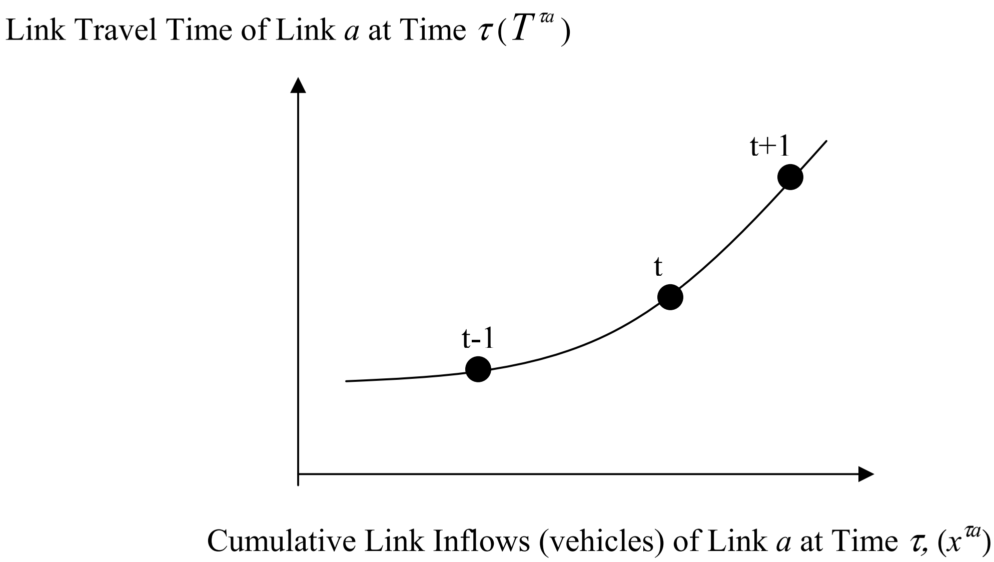

Figure I5.1: Computation of Derivative for Link Marginal Cost

Illustrative Example

Consider a particular link, Link *a*, from RouteSim (a simulation model in VISTA). The time-dependent link travel times and associated cumulative link inflows for the three successive time steps are shown in Figure I5.1. The numerical values are:

At time t-1, link inflow = 100 vehicles and link travel time = 1500 sec
At time t, link inflow = 250 vehicles and link travel time = 2500sec
At time t+1, link inflow = 400 vehicles and link travel time = 6000 sec.

The link marginal congestion cost and associated MCP toll are determined as follows.

First, solve the following system of equations to determine parameters of a quadratic function (time-dependent link performance function).

$$A(100)^2 + B(100) + C = 1500$$
$$A(250)^2 + B(250) + C = 2500$$
$$A(400)^2 + B(400) + C = 6000$$

The solution of this system of equations is: A = 0.0555, B = -12.777, C = 2222.222.

The link marginal congestion cost of link *a* at time *t* is a gradient of the quadratic curve at point (250, 2500), which is 14.973 seconds/vehicle. With the VOTT of $10.00 / vehicle-hour, the MCP toll of link *a* at time *t* is 4.16 cents plus an existing flat toll (if any).

Note: The system of equations is

$$AX_1^2 + BX_1 + C = Y_1$$
$$AX_2^2 + BX_2 + C = Y_2$$
$$AX_3^2 + BX_3 + C = Y_3$$

where A, B and C are variables and X and Y are data. Then, the solution is determined from the following expressions:

$$L_1 = \frac{X_1 + X_2}{X_1 X_2}, L_2 = \frac{X_1 + X_3}{X_1 X_3}, R_1 = \frac{Y_1 X_2^2 - Y_2 X_1^2}{X_1 X_2 (X_2 - X_1)}, R_2 = \frac{Y_1 X_3^2 - Y_3 X_1^2}{X_1 X_3 (X_3 - X_1)}$$

$$C = \frac{R_1 - R_2}{L_1 - L_2},\ B = R_1 - CL_1,\ A = \frac{Y_1}{X_1^2} - \frac{B}{X_1} - \frac{C}{X_1^2}.$$

The gradient of this quadratic function at point (X_2, Y_2) is: $\frac{dY}{dX}(X_2, Y_2) = 2AX_2 + B$. Then, the MCP toll at time *t* (associated with point (X_2, Y_2)) is $2AX_2 + B$ + existing flat toll.

Peeta and Mahmassani (1995) suggested that the consideration of small time intervals (on the order of a few seconds) may cause some instability in the curves because the VOTTs and the number of vehicles in successive intervals may exhibit “jumps” at certain times. Hence, the length of the time interval between successive data points involves trade-offs between the accuracy and robustness of the curves. To achieve stability in the curves, the simulation of 6-second time intervals may be too small for updating OD paths , since no appreciable change takes place in the system in such a short duration. In the implementation of the solution algorithm, paths are updated every assignment interval (i.e., every 10 minutes for the DFW network). The marginal values may be computed for assignment intervals only and not for simulation intervals, thereby reducing the computational burden of the path-processing step.

Appendix I6: Modified DTA Schemes

The DTA scheme was modified for the analyses of the status quo and the MCP-on-freeway. First, the existing DTA scheme is described, followed by the modified schemes for the two scenarios.

No Pricing

The MSA-based DTA is called the MSA-DTA algorithm as discussed in Appendix I2. It is briefly explained here. For the no pricing case, the MSA-DTA algorithm iteratively runs the following seven modules in sequence until convergence:

1. RouteSim,
2. time-dependent link travel time computation,
3. TDSP,
4. all-or-nothing vehicle assignment,
5. path update,
6. MSA on link flows, and
7. check convergence.

The computational bottleneck is the TDSP algorithm. After 5 iterations of DTA, we assumed that there is a sufficiently large number of paths generated for each OD pair. Then, the module "update-cost-dta" in VISTA was executed that ran the following six modules in sequence:

1. RouteSim,
2. time-dependent link travel time computation,
3. path cost update,
4. all-or-nothing vehicle assignment,
5. MSA on link flows, and
6. check convergence.

An iteration of update-cost-dta was much faster than an iteration of MSA-DTA because the TDSP was replaced by a module that simply updates costs of generated paths. This update-cost-dta ran until it achieved convergence.

Status Quo

For the status quo scenario (with flat tolls on existing toll roads), the MSA-DTA and update-cost-dta run the same modules in sequence as in the no pricing scenario with two changes. First, replace the TDSP with the TDLC. Second, after RouteSim, the time-dependent tolls (time of -1 for flat toll) are read in and converted into time penalty by the VOTT. Thus, MSA-DTA runs:

1. RouteSim,
2. time-dependent toll input,
3. time-dependent link generalized cost computation,
4. TDLC,
5. all-or-nothing assignment,
6. path update,
7. MSA on link flows, and

8. check convergence.

The update-cost-dta runs:

1. RouteSim,
2. time-dependent toll input,
3. time-dependent link generalized cost computation,
4. path cost update,
5. all-or-nothing assignment,
6. MSA on link flows, and
7. check convergence.

MCP-On-Freeways

For the MCP-on-freeways scenario, the MSA-DTA and update-cost-dta ran the same modules in sequence as in the status quo scenario with an addition of a new module. The new module, MCP computation, was to compute the link marginal congestion costs on the tolled links, then convert these costs to equivalent toll, and finally overwrite the time-dependent tolls for the next MSA iteration. Thus, MSA-DTA runs:

1. RouteSim,
2. MCP computation,
3. time-dependent toll input,
4. time-dependent link generalized cost computation,
5. TDLC,
6. all-or-nothing assignment,
7. path update,
8. MSA on link flows, and
9. check convergence.

The update-cost-dta runs:

1. RouteSim,
2. MCP computation,
3. time-dependent toll input,
4. time-dependent link generalized cost computation,
5. path cost update,
6. all-or-nothing assignment,
7. MSA on link flows, and
8. check convergence.