# Fiscal Year 2009 Task Reports

final

**report**

*prepared for*

**National Capital Region Transportation Planning Board (TPB)**

*prepared by*

**Cambridge Systematics, Inc.**

*with*
Gallop Corporation
Vision Engineering and Planning, LLC

*November 20, 2009*

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# Fuel Prices in Travel Models

# task memorandum

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# Fuel Prices in Travel Models

## 1.0 Introduction

After remaining fairly constant with small seasonal variations for most part of the last decade, fuel prices have more than doubled since early 2003. Media and other recent reports have been suggesting that increased fuel prices started to affect travel demand and consumers were changing their travel behavior to adapt to the higher fuel price regime.

Drawing on the common sense hypothesis that fuel prices have a direct impact on travel demand, it was deemed a useful exercise to investigate the effects of fuel prices on travel demand. Given the current situation (declining fuel prices amidst a weak economic environment), it is more difficult to analyze the effects of the price spike experienced in 2008. Any changes in aggregate travel behavior cannot be attributed to fuel prices alone amidst a slow economy. Such an exercise would require sufficient time lag to get meaningful data and results. Observing short-term adjustments provides useful insights, but for travel forecasting purposes, long-term effects are more important.

This memorandum tries to capture the essence of the interplay between fuel prices and travel demand based on the current literature and state of the practice on treatment of fuel prices in travel demand models. The rest of this technical memorandum is divided into three sections. Section 2.0 reviews the state of practice in the transportation industry followed by a discussion on fuel prices and its effects on travel behavior in Section 3.0. Section 4.0 discusses ways to incorporate fuel prices in travel demand models and the challenges involved.

## 2.0 Review of Practice

Traditionally, fuel prices enter travel demand models as a component of automobile operating cost in the mode choice phase. Automobile operating costs vary widely across geography and due to uncertainty on what costs are perceived as relevant while choosing the automobile mode. Typical components of automobile operating costs are fuel cost, wear and tear, and maintenance. Fixed costs like vehicle ownership cost and insurance are generally not considered as part of the automobile operating cost. Historically, automobile operating costs have been small in magnitude and, even with a spike in fuel prices, relative changes in automobile operating cost on a per-mile basis would be relatively small.

Treating fuel prices as a standalone item does not reflect a true picture for future forecasts, since it disregards fuel efficiency improvements over time. Higher fuel prices also drive the automobile industry towards improved vehicle technology and fuel efficiency. Faced with higher automobile operating costs, travelers are expected to shift towards buying more fuel-efficient vehicles in the long run.

When trying to capture the effect of fuel prices on travel demand, understanding traveler's response regarding number of trips and destination choice is important. These cost variables generally only appear in the mode choice model in traditional four-step models and hence the effect of fuel prices on trips generated and destination choice is not captured.

The automobile operating cost in the National Capital Region Transportation Planning Board travel forecasting model is made up of direct expenditures associated with an automobile trip (e.g., fuel, oil, maintenance, and wear and tear) and no ownership costs. The current model assumes a fixed 10 cents-per-mile (in 1994 dollars) automobile operating cost while in the earlier version of the model, automobile operating cost assumptions changed every five years with 9.1 cents-per-mile (in 1994 dollars) in 1994 to 7.1 cents-per-mile (in 1994 dollars) in 2030. Using a fixed automobile operating cost for future year forecasts assumes that fuel efficiency and other technology innovations nullify increases in fuel prices. It does not take into account the fact that vehicle technology improvements lag fuel prices substantially and fleet changes occur only in long term. It also fails to capture short-term adjustments made by travelers and the long-term effects of such adjustments. As such, the traditional four-step modeling process fails to capture the essence of many adjustments in response to fuel price changes, since fuel prices are assumed to only alter mode choice.

To better understand the problem at hand requires a historical perspective on the causality of fuel price changes and travel behavior adjustments. The following section details the impacts of changing fuel prices on overall travel behavior.

## 3.0 Changing Fuel Prices and its Impact on Travel Behavior

Fuel prices have traditionally been volatile, with high monthly and seasonal variations. Looking at historical fuel prices, as illustrated in Figure 1,[1] two fuel price spikes stand out – the oil crisis of the 1970s and the current decade. The soaring fuel prices in the 1970s led to advances in vehicle technology to improve fuel efficiency as well as considerable changes in travel behavior. Travelers' responses included reduced driving, purchasing more fuel-efficient vehicles, mode shifts, and changing residential location.

After fluctuating around a fixed average for most of the last decade, fuel prices started soaring early this decade. Along with an upward trend, monthly and seasonal variation in fuel prices also have become more prominent since 2003 (see Figure 2).[2] Even with a doubling of real fuel prices since 2003, fuel price increases over this period have not seemed to induce the behavioral adjustments observed during the 1970s. While a 20 percent increase in fuel price resulted in 6 percent less consumption during the 1970s, a similar increase yielded only one percent less consumption during the most recent fuel

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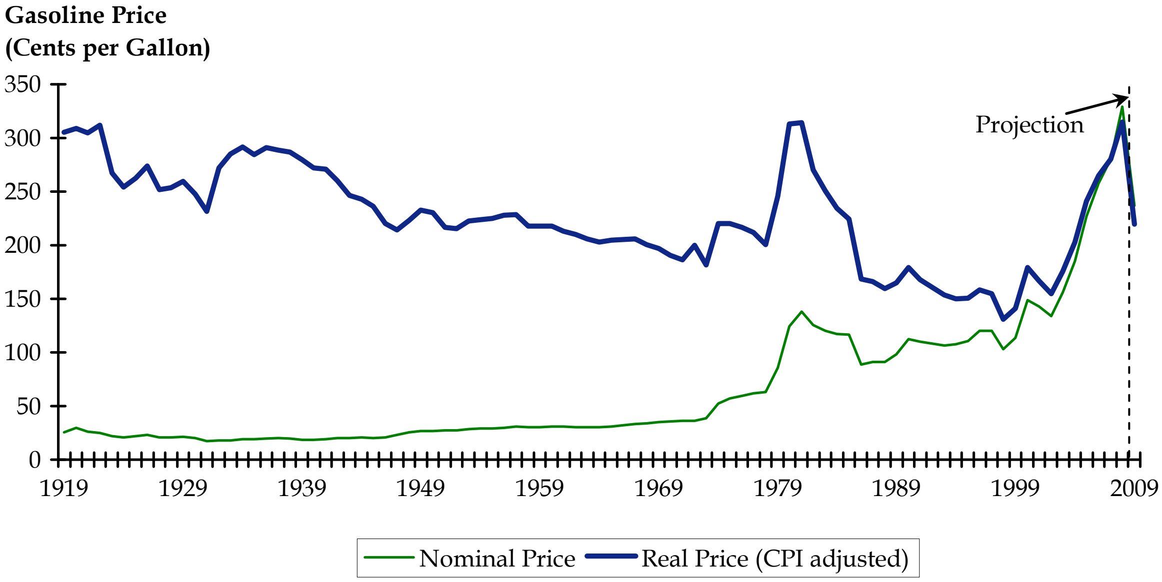
[1] Real gasoline price is adjusted to Consumer Price Index (Base Year = 2007).

[2] Real gasoline price is adjusted to Consumer Price Index (Base Month = November 2008).

price increase. A recent study[3] on the impact of fuel prices on consumer behavior and traffic congestion (INRIX, 2008) suggests significant changes in driver behavior in response to rising fuel prices. Two-thirds of the survey respondents indicated that they reduced driving due to higher fuel prices. The survey results also show increased trip chaining and a significant reduction in discretionary driving. More importantly, while cumulative vehicle miles traveled (VMT) from January to September 2008 is 3.5 percent less than the observed VMT during the same period in 2007, the changes have translated into an approximately 26 percent reduction in peak-hour congestion.[4] Fuel prices also had significantly higher influence in sprawling cities like Los Angeles and Atlanta rather than denser, transit-rich cities like Washington, New York and Chicago. This may be explained in part by the unused access-to-transit capacities (especially, park-and-ride lot capacity) in the sprawling cities as well as lower average income levels of the population. However, the reduced congestion and faster travel times are short-term responses to higher fuel prices and may not persist in the absence of a sustained higher fuel price regime.

**Figure 1. Annual Average Retail Gasoline Prices**
*1919-2009*



Source: http://www.eia.doe.gov/emeu/steo/pub/fsheets/real_prices.xls.

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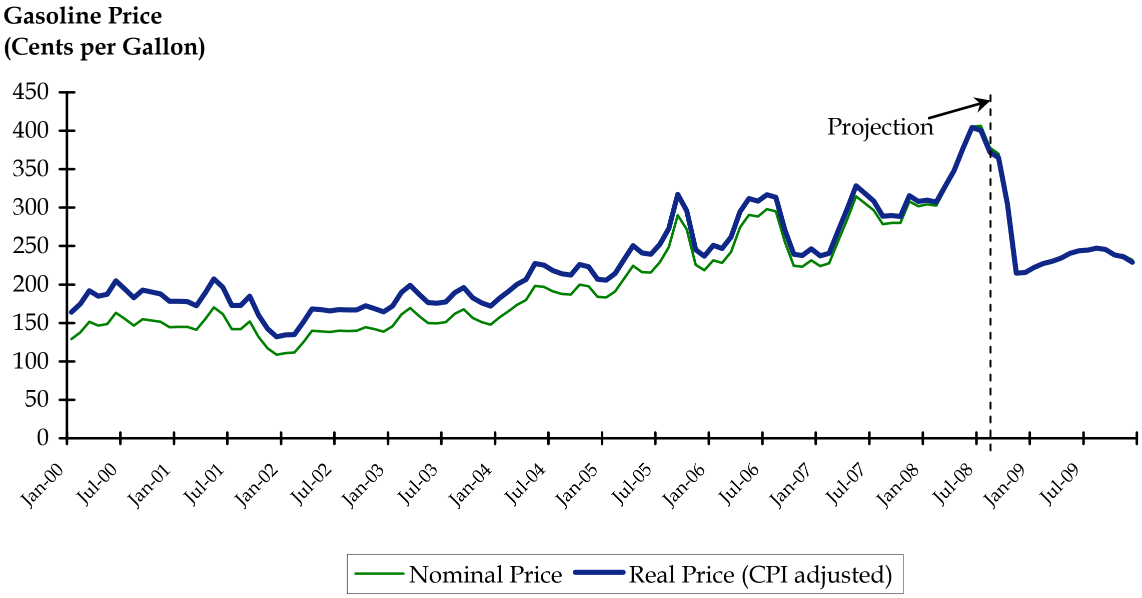
[3] This study is based on the Harris Interactive Online Survey conducted between October 8-10, 2008 among 2,212 U.S. adults, 1,977 of whom drove an automobile.

[4] Federal Highway Administration, *Traffic Volume Trends*, September 2008. (Source: http://www.fhwa.dot.gov/ohim/tvtw/08septvt/index.cfm).

**Figure 2. Monthly Average Retail Gasoline Prices**
*2000-2009*



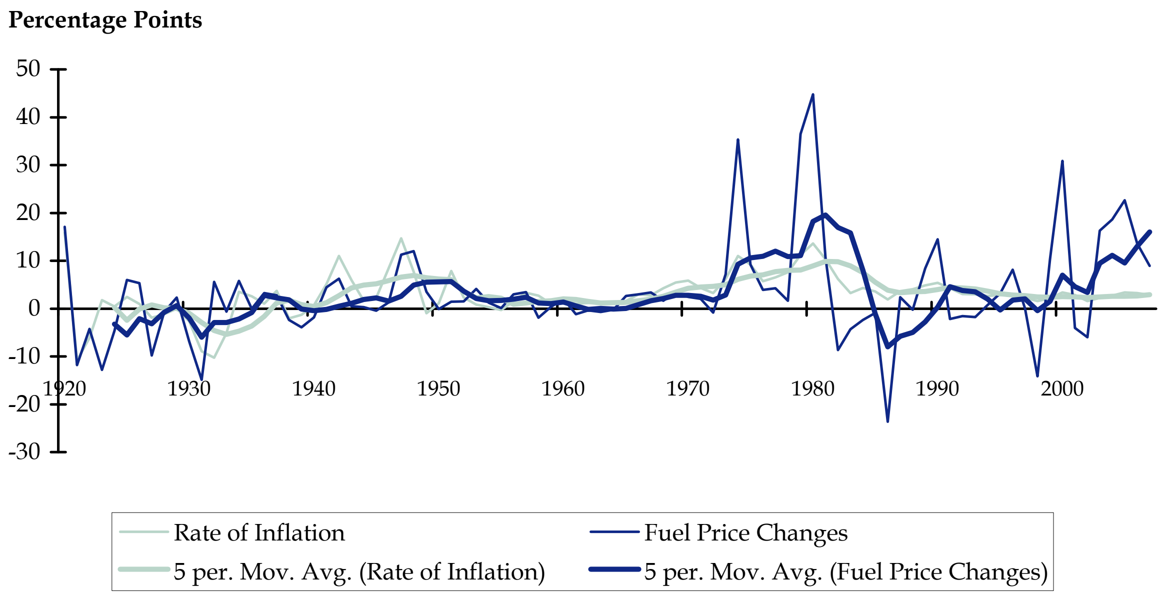
Source: http://www.eia.doe.gov/emeu/steo/pub/fsheets/real_prices.xls.

## Fuel Prices and Inflation

Another important aspect of fuel price changes is the correlation between fuel prices and the rate of inflation. While inflation is influenced by a wide range of economic factors, the historical trends suggest slight correlation in fuel price changes and inflation (see Figure 3). An increase or decrease in fuel prices drives inflation upwards or downwards, respectively. Except for the oil crisis of the 1970s and the recent fuel price increase, fuel prices have increased at a slower rate than inflation. A 35.4 percent increase in fuel prices from 1973 to 1974 resulted in inflation climbing from 6.2 to 11.0 percentage points. Higher fuel prices during the second oil crisis of the 1970s (fuel prices rose by 37 and 45 percent during 1979 and 1980, respectively) also resulted in very high rates of inflation (11.2 and 13.6 percent inflation rate in 1979 and 1980, respectively). However, increases in fuel prices over the past ten years have not resulted in similar changes in the rate of inflation. While fuel prices doubled from year 2002 to 2007, the rate of inflation grew from 1.6 percent to 2.9 percent during the same period.

The impact of changes in fuel prices on travel behavior is likely to be influenced by the concurrent rates of inflation. However, given the wide range of economic and geopolitical factors influencing fuel prices as well as the rate of inflation, it is difficult to forecast either with reasonable levels of confidence.

**Figure 3. Annual Rate of Inflation versus Annual Fuel Price Changes**
*1920-2007*



Source: http://www.eia.doe.gov/emeu/steo/pub/fsheets/real_prices.xls; http://www.inflationdata.com/inflation/Inflation_Rate/HistoricalInflation.aspx.

## Factors Affecting Fuel Price Sensitivities

Travel behavior sensitivity to fuel price depends on a variety of factors. Some of the key factors are:

- **Trip and Traveler Characteristics –** In general, work-related trips and peak-period trips are less elastic than shopping/recreational trips and off-peak-period trips, respectively. A literature survey on transportation elasticities by Litman (2008) suggests that urban commute trips have an elasticity of -0.3 to -2.9 with respect to out of pocket expenses, compared to -2.7 to -3.2 for shopping trips. Higher-income travelers as well as business travelers are less sensitive to price changes than lower-income travelers and nonbusiness travelers, respectively.
- **Time Period –** Fuel price elasticities increase with time. Large and dramatic spikes in fuel prices tend to be less elastic than slow and steady changes. Short-term[5] elasticities

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[5] Short term is generally referred to as one period of the data, and is generally less than two years in transportation studies.

are considerably different than long-term[6] elasticities, as people have more time and resources to adapt in the longer term. In the short term, travelers may respond to price increase by more efficient travel behavior, i.e., trip chaining, efficient driving, and changing travel times. In the long-term, consumers may shift to more fuel-efficient vehicles or reduce commute lengths by relocating, moving to more accessible neighborhoods, and even changing workplaces. Long-term elasticities, in general, are two to three times higher than the respective short-term elasticity (Goodwin et al., 2004).

- **Quality and Price of Other Alternatives –** The quality and price of other alternatives influence the sensitivity to fuel prices. Availability of an alternative mode, route, or destination with comparable travel time and quality increases sensitivity to price. For example, auto users' sensitivity to fuel price in a city with reliable and frequent transit service would be higher than in an automobile dependent area. Similarly, presence or absence of a light rail option considerably affects auto users' price sensitivity.

## Fuel Price Elasticities

Sensitivity is measured in terms of elasticity by economists. Arc elasticity is most commonly used for transportation analyses. Arc elasticity of demand (*Q*) with respect to price (*P*) is defined as follows:

$$Arc\ Elasticity = \frac{\Delta \ln Q}{\Delta \ln P}$$

Elasticity values are good only for the range of values observed and hence should not be used for forecasted data points which are unobserved in the existing dataset. Also, most of the reported elasticities are static elasticities and lack the valuable information that users have to adapt to the changing environment. Following is a brief discussion on elasticity of various transportation demand components with respect to fuel prices.

**Vehicle Ownership –** If higher fuel prices persist for a long period of time, consumers are likely to replace the fleet with more fuel-efficient cars. Such a shift would be gradual and might not be substantial if the fuel prices drop back down to lower levels. New vehicle sales data is the best reflection of such a shift. After a steady increase in market share of trucks for the last two decades, relative to all new passenger vehicles, a downward trend started in 2004 (see Figure 4). The market share of SUVs (largest share among trucks), which had shown the highest growth in the last couple of decades, also started to show a downward trend since 2004. The effect has been even more prominent in the last one year. The market share of new car sales has increased from 47.0 to 51.7 percent while that

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[6] Long term generally refers to an asymptotic end state, and is generally 5 to 10 years in transportation studies.

of light trucks has decreased from 53.0 to 48.3 percent from 2007 to 2008.[7] A Congressional Budget Office (CBO) study[8] suggests that a 20 percent increase in the price of gasoline would increase the market share of cars (versus light trucks) by 2.6 percentage points. The consumers' response also is affected by automobile pricing strategy and overall fuel economy in the long run.

Fuel price increases not only affect vehicle type choice but also vehicle ownership decisions. Litman (2008) suggests the vehicle ownership elasticity with respect to fuel price to range from -0.2 to 0.0 in the long term. Goodwin et al. (2004) surveyed 69 empirical studies on the effect of income and price on transportation components to estimate the ranges of elasticity of various measures of demand. Their observation on elasticity of vehicle stock is shown in Table 1.

### Table 1. Vehicle Stock Elasticity with Respect to Fuel Price

| | **Dynamic Estimation Using Time Series Data** | | **Static Estimation** |
|---|---|---|---|
| | **Short Term** | **Long Term** | **Average** |
| Mean Elasticity | -0.08 | -0.08 | -0.06 |
| Standard Deviation | 0.06 | 0.06 | 0.08 |
| Range | -0.21, -0.02 | -0.63, -0.10 | -0.13, 0.03 |
| Number of Estimates | 8 | 8 | 3 |

Source: Goodwin et al., 2004.

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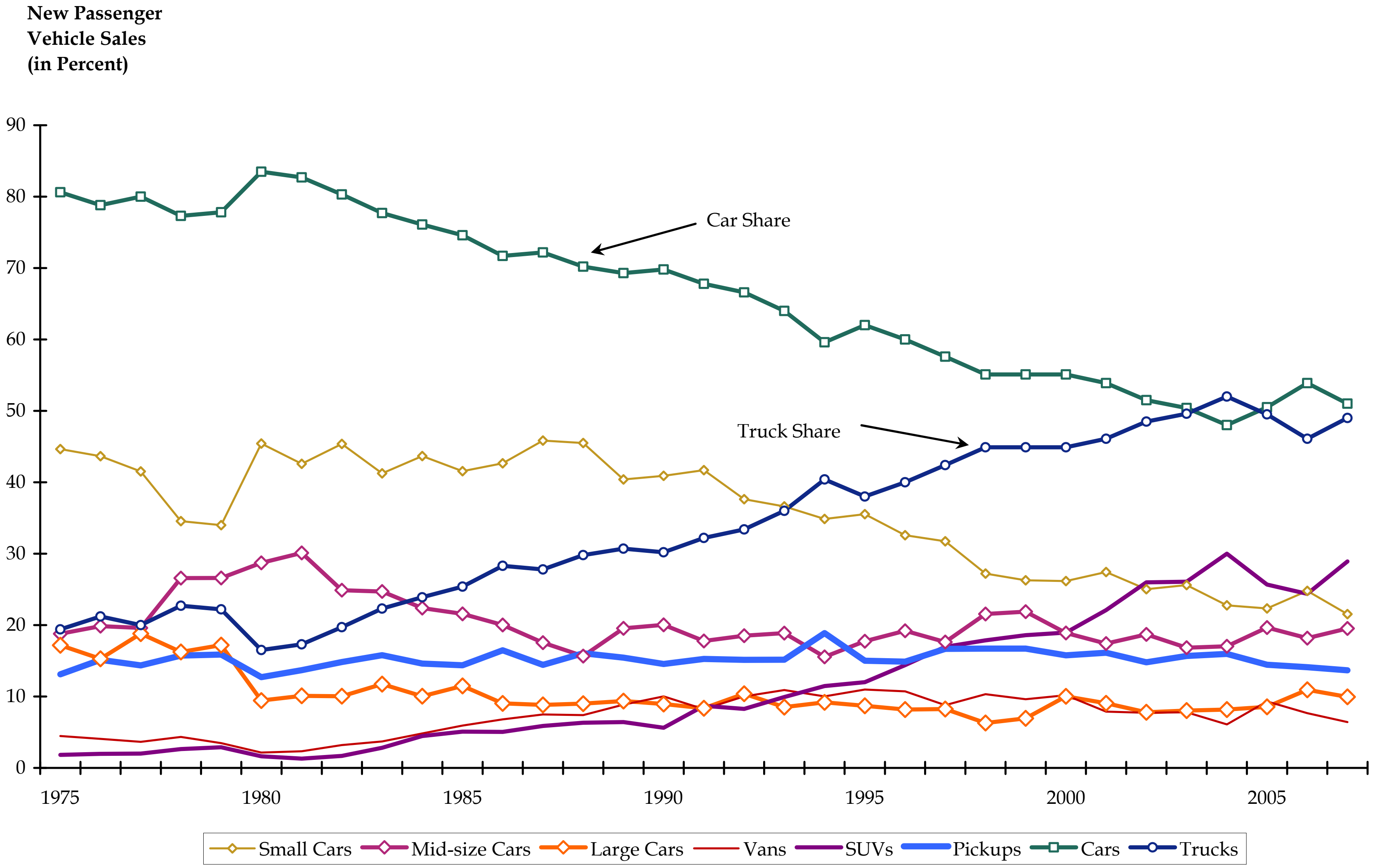
[7] Market shares are based on 2008 (YTD) versus 2007 (YTD) sales data of light trucks and cars (source: http://online.wsj.com/mdc/public/page/2_3022-autosales.html#autosalesA).

[8] This represents only the short-term response and could be considerably affected by automobile pricing strategy and improved fuel efficiency in the long term.

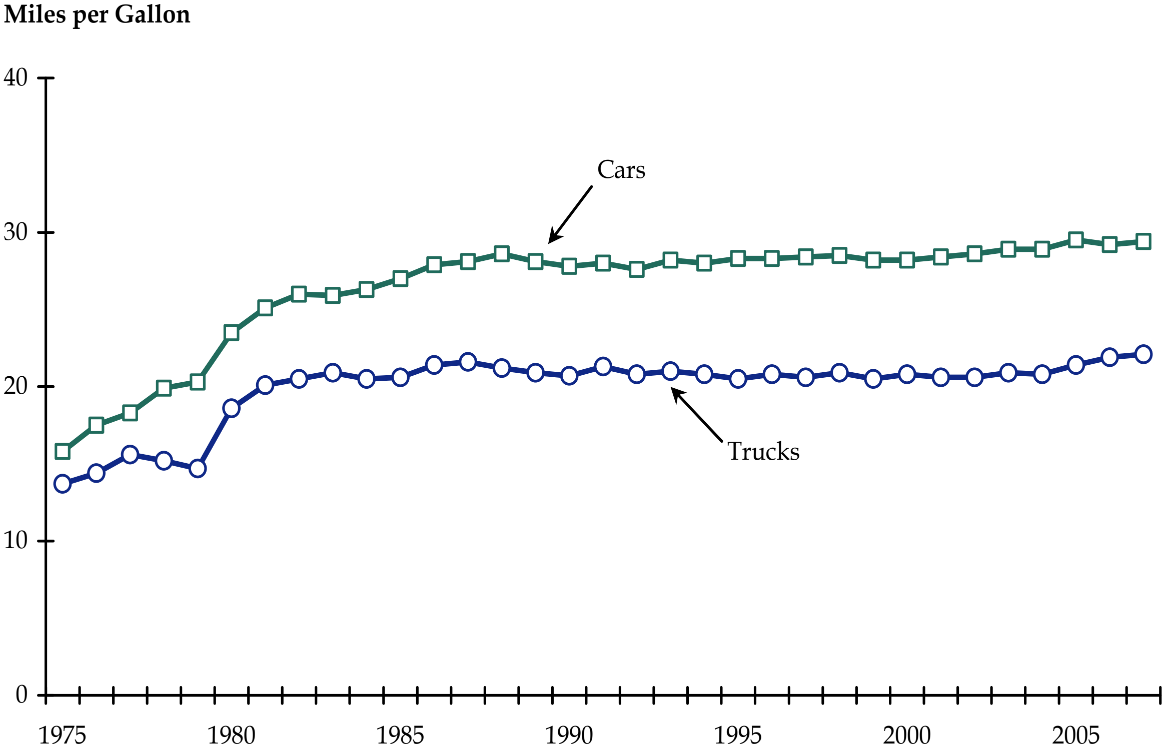
# Figure 4. New Passenger Vehicle Market Shares
*1975-2007*



Source: http://epa.gov/otaq/cert/mpg/fetrends/420r08015.pdf.

**Fuel Consumption and Efficiency –** Changes in fuel economy are significantly affected by fuel prices. After negligible improvement in fuel efficiency of new vehicles in the last decade, it began showing improvement starting in 2004 in response to higher fuel prices (see Figure 5). Average fuel economy of new cars increased from 28.9 miles per gallon (mpg) in 2004 to 29.5 mpg in 2005 before dropping down to 29.4 mpg in 2007. Improvement in the fuel economy of new trucks has been more prominent, increasing from 20.8 mpg in 2004 to 22.1 mpg in 2007. An improvement in the fuel efficiency of the new passenger vehicle fleet compensates for the fuel price increases to some extent. Table 2 review results of selected studies on elasticity of fuel consumption and efficiency with respect to fuel price.

**Figure 5. Fuel Efficiency of New Passenger Vehicles**
*1975-2007*



Source: http://epa.gov/otaq/cert/mpg/fetrends/420r08015.pdf.

### Table 2. Elasticity of Fuel Efficiency and Consumption with Respect to Fuel Price

| Study | Short Term | Long Term |
|---|---|---|
| **Fuel Efficiency Elasticity with Respect to Fuel Price** | | |
| Litman (2008) | – | -0.45, -0.35 |
| Small and Van Dender (2007) | -0.031 | -0.193 |
| **Fuel Consumption Elasticity with Respect to Fuel Price** | | |
| Espey (1998) | -0.26 | -0.58 |
| Graham and Glaister (2002) | -0.2, -0.3 | -0.6, -0.8 |
| Small and Van Dender (2007) | -0.074 | -0.363 |

Source: Goodwin et al., 2004; Small and Van Dender, 2007.

**Vehicle Miles Traveled –** Vehicle miles traveled, as a measure of total travel demand, is expected to respond to fuel price increases. Total highway travel in the United States grew steadily at 3.2 percent annually from 1970 to 1995. The rate dropped to 2.1 percent from 1995 to 2005 (Small and Van Dender, 2007). However, a recent study in California (SACOG, 2008) suggests that VMT has decreased on an annual basis for the last three years, and if the trend continues, would result in a 3 percent decrease in VMT per capita in 2008 from 2007. The overall changes in the economy also play a significant role in total VMT and hence, these shifts cannot be attributed to the effects of fuel price changes alone. The range of VMT elasticity with respect to fuel price is shown in Table 3.

### Table 3. Elasticity of Vehicle Miles Traveled with Respect to Fuel Price

| | Dynamic Estimation Using Time Series Data | | Static Estimation |
|---|---|---|---|
| | Short Term | Long Term | Average |
| Mean Elasticity | -0.10 | -0.29 | -0.31 |
| Standard Deviation | 0.06 | 0.29 | 0.14 |
| Range | -0.17, -0.05 | -0.63, -0.10 | -0.54, -0.13 |
| Number of Estimates | 3 | 3 | 7 |

Source: Goodwin et al., 2004.

**Other Elasticities –** Table 4 shows the broad effects of a 10 percent increase in real fuel prices as reported by Goodwin et al. (2004), based on a literature survey.

## Table 4. Effects of Increase in Fuel Price

| | Short Term | Long Term |
|---|---|---|
| Traffic Volume | -1% | -3% |
| Fuel Consumed | -2.5% | -6% |
| Fuel Efficiency | 1.5% | 4% |
| Vehicle Stock | -1% | -2.5% |

Source: Goodwin et al., 2004.

**Transit Ridership –** Transit ridership is highly affected by fuel price increases as it induces fare increases along with a mode shift in favor of transit modes. Transit ridership is fairly inelastic with respect to fare in the short term and for peak-period trips. Transit price elasticities for off-peak periods are almost twice as high as peak period. It should be noted that in the Washington, D.C. area, transit ridership is said to be less sensitive to fare increases than in other areas due to the high levels and availability of employer-provided transit fare subsidies. General elasticity estimates of transit ridership with respect to transit fare and auto costs are shown in Table 5.

## Table 5. Transit Mode Elasticity Estimates

| | Short Term | Long Term |
|---|---|---|
| Transit Ridership w.r.t. Transit Fare (Peak) | -0.15, -0.3 | -0.4, -0.6 |
| Transit Ridership w.r.t. Transit Fare (Off-Peak) | -0.3, -0.6 | -0.8, -1.0 |
| Transit Ridership w.r.t. Auto Operating Cost | 0.05, 0.15 | 0.2, 0.4 |
| Automobile Travel w.r.t. Transit Fare | 0.03, 0.1 | 0.15, 0.3 |

Source: Litman, 2008.

**Freight Movement –** Higher fuel prices are likely to have a considerable impact on freight movement. Higher fuel prices put trucks at a disadvantage and may result in mode shifts from trucks to the comparatively fuel-efficient rail mode. Norrell (2008) suggests a positive correlation between diesel price and rail market share. However, lack of rail coverage and intermodal terminal connections limit the mode shift to rail.

In the short term, cost considerations of fuel efficiency are likely to be secondary to improving operating efficiency in terms of loading and logistics. However, in the long run, sustained higher fuel prices will induce improvements in vehicle technology and logistics, movement towards more efficient fuels, and closer proximity in supply and demand.

# ■ 4.0 Fuel Prices and Travel Demand Models

The environment of uncertain fuel prices raises questions regarding long-term forecasts based on existing travel demand models. If fuel prices remain high for a prolonged period, induced changes in travel behavior would be expected. However, a lack of data in support of probable behavioral responses limits the viability of modeling long-term impacts of fuel price increase. To account for fuel price changes within travel demand models, also requires forecasting future fuel prices.

## Forecasting Fuel Prices

The geopolitical nature of the factors affecting fuel prices makes it extremely hard to forecast future prices. Historical fuel prices do not reveal any predictable trend. Most underlying factors affecting fuel prices are impossible to predict. Some suggestions on forecasting future year fuel prices are as follows:

- **Delphi Approach –** The Delphi Approach is a systematic, interactive forecasting method, relying on a panel of independent experts. It is based on the assumption that forecasts from a structured group of experts are more reliable than unstructured individuals/groups. Individual experts answer a set of questions in various rounds, adjusting their answers based on feedbacks from the previous rounds. The process is ended once a consensus is achieved or a predefined criterion on the stability of results or number of rounds is met. One of the weaknesses of the Delphi Approach is that consensus may not be achieved easily or in timely fashion. Identifying and convening a panel of experts can be a time-consuming process in itself. Also, consensus forecasts from a panel of experts are no guarantee of a good forecast. Ignorance and misinformation may result in biased predictions.

- **Adjusting Price Estimate Based on Inflation –** Future fuel prices can be forecasted using the current fuel price and adjusting it slower or faster than the inflation rate. This method is based on the assumption that relative fuel prices remain fairly constant.

- **Linear Regression –** Historical trends can be extrapolated to forecast future prices. Such an approach should not be used for long-term forecasts.

- **Sophisticated Econometric Models –** Time series and other complex econometric models can be used to forecast fuel prices. However, given the volatile nature of fuel prices, most of the available modeling techniques fail to deliver reliable future forecasts.

- **Using the Base Year Fuel Price –** Current fuel price is widely considered as the best estimate of future year fuel prices and using current fuel prices is the most widely accepted practice. Most of the other forecasting methods are considered too speculative to be reliable.

## Potential Travel Model Considerations

Travel demand models have limited capability to model the potential consequences of higher fuel prices. Limited data availability on large-scale behavioral changes in response to higher fuel prices is a restriction on modeling efforts. However, identifying the potential impacts of a higher fuel price regime could be helpful in accounting for the uncertainty involved with respect to model input variables.

- **Changes in the Land Use Pattern –** If higher fuel prices persist for a long time, people may respond to higher travel costs by relocating closer to work and/or shopping locations. In the long run, this may cause a realignment of land use patterns and densities.

- **Reduction in Total Trips –** Reduction in total trips is likely, with reduced weekend nondiscretionary trips and trips of similar nature. Travelers may combine trips to eliminate the need for such trips.

- **Increased Trip Chaining –** Trip chaining is going to become more and more frequent to reduce the burden of increased automobile operating costs.

- **Changes in Trip Length –** Trip chaining and changing land use patterns may drive average trip lengths downward.

- **Increased Transit Patronage –** Increases in the price of owning and operating automobiles may drive automobile users to shift to a transit mode, given the availability of a reliable and frequent transit mode. However, travelers' travel-time sensitivities may be a check on the shift towards transit modes.

- **Increased Transit Costs –** Higher fuel prices are likely to drive transit fares upwards. However, transit ridership is known to be fairly inelastic with respect to transit fares, especially in the Washington D.C. region.

- **Changes in Household Expenditure Patterns –** Sustained higher fuel prices also may result in households changing their expenditure patterns to avoid having to make large adjustments to their travel behavior.

- **Changes in Fuel Efficiency –** Automobile companies are likely to respond to higher fuel prices with technology improvements resulting in a more fuel-efficient vehicle fleet. Improvement in fuel economy and a shift towards a more fuel-efficient fleet is a long-term response to fuel price increases.

- **Changes to Toll Road Usage –** Increased fuel prices are likely to have an impact on total toll road usage. However, the impact depends on the sensitivity of the toll road user segment to higher fuel prices and automobile operating costs.

- **Changes in the Departure/Arrival Times –** Travelers' are likely to modify their departure/arrival times to avoid heavy congestion in the wake of increasing automobile operating costs. It is one of the most common responses in the short term.

## Data Constraints and Modeling Approaches

Travel demand models lack the emphasis on modeling the effect of fuel prices partly because large-scale behavioral changes in response to fuel price changes have not been observed. The data required to model the effects of the higher fuel prices earlier this year is either not yet available or potentially inconclusive. And the most recent sudden downturn in fuel prices coupled with the current slowdown in the economy render such data collection efforts infeasible in the near term. In an uncertain economic environment, establishing the causality of travelers' responses is particularly difficult. Moreover, the effect of market uncertainties and innovations in driving automobile operating costs is speculative.

Sustained higher fuel prices may drive a greater need of incorporating the effects of fuel prices in travel demand models. Following are a few possible modeling approaches that would be helpful in partially understanding the dynamics of fuel prices and travel:

- **Integrated Land Use and Transportation Microsimulation Model –** Use of an integrated microsimulation-based land use and transportation model to incorporate a feedback mechanism between fuel costs and land use/demographics could be helpful in accounting for changes in the travel behavior as a response to fuel costs. The key to such modeling approaches would be identifying and understanding the numerous land use and transportation dynamics associated with the cost of travel. However, microsimulation models are generally data intensive and the availability of data could be a concern. Furthermore, while it would provide useful insights into the dynamics of fuel prices and travel behavior, the uncertain nature of fuel prices and economic environment along with unreliable forecasts for the same severely restricts the forecasting abilities of even the most sophisticated travel demand models. Hence, forecasts based on such models are only as good as the ability to predict the underlying future fuel prices.
- **Using a Multi-Scenario Analysis to Predict the Spectrum of Probable Future Scenarios –** The easiest approach is to use the current travel demand models to forecast a range of probable future scenarios, employing a multi-scenario analysis. Since forecasting components of automobile operating cost is difficult, creating a spectrum of future scenarios using extreme forecasts of the input variables (or a Monte Carlo simulation method) would yield useful insights.

# ■ 5.0 Conclusions

While the fuel price increases in the 1970s resulted in considerable changes in travel behavior and improvements in fuel efficiency, such changes were not observed during the recent price increases. The highly volatile nature of fuel prices make data collection efforts to gauge the magnitude of travel behavior changes in response to fuel price changes difficult. Also, the ability to track the causality of travel behavior changes is affected by the interaction of fuel prices, rate of inflation, and overall economic environment.

Forecasting these is a difficult task in the absence of clear historical trends and given the unpredictable nature of the influencing factors.

While most travel attributes are sensitive to fuel prices to some extent, traditional travel demand models lack the ability to comprehensively address the effect of fuel prices. Furthermore, in view of the data constraints and volatility of fuel prices, any changes in the existing modeling practice may not be rewarding enough to justify the required efforts and investment. Using the current models in place to conduct sensitivity analyses with respect to a wide range of automobile operating cost scenarios should help provide key insights on the effects of fuel price changes. Given the constraints, employing a multi-scenario analysis to predict a spectrum of possible future scenarios while using reasonably robust model structures and relying on professional judgment is probably the best way forward.

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# Recommended Approach to Near-Term Model Enhancements

task

**memorandum**

*prepared for*

**National Capital Region Transportation Planning Board**

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*November 20, 2009*

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# Recommended Approach to Near-Term Model Enhancements

## 1.0 Introduction

The purpose of this task and its resulting technical memorandum is to explore possible directions for near-term model enhancements while keeping an eye towards the next steps in long term model development. The current state-of–the-practice travel demand forecast models, like the current model used by the National Capital Region Transportation Planning Board (TPB), follow a four-step sequential process that tracks trips at an aggregated level through the transportation decision process. While the four-step process performs reasonably well in representing and forecasting aggregate system- and corridor-level travel demand, the process is unable to respond to policies that are of increasing interest today. In particular, four-step models cannot adequately address the following: road and congestion pricing; time-specific policies; improvements in traffic operations and ITS deployment; freight and goods movement; peak spreading; and highly congested networks (TRB, 2007).

In response to the need to model these complex policy alternatives and traffic operation scenarios, techniques have been developed and are starting to be implemented that focus on a more disaggregate level of choice and incorporate greater behavioral realism. Four-step models using tours as the unit of analysis and more disaggregate activity-based models are becoming more applicable. A highlighting of this approach was, indeed, the impetus for developing this review (the Appendix contains a copy of a memorandum on this subject received by TPB staff as well as comments specific to that memorandum prepared by Cambridge Systematics). However, four-step tour-based models applied at the zonal level, but allowing for multiple purposes and multiple stops within each trip, are limited in their ability to address today's policy concerns.

Consequently, all Metropolitan Planning Organizations (MPOs) that recently moved toward more advanced modeling systems have chosen to implement an activity-based model. Activity-based models treat travel as a demand derived from the desire and need to participate in activities. Therefore, the activity-based approach attempts to capture the behavioral basis behind households' and individuals' decisions to participate in specific activities at certain times and places. By modeling individual participation in activities, and incorporating the sequences of activity throughout the course of the day, such an approach can address complex issues. It is for this reason that many major MPOs are moving to these new frameworks and/or currently developing work programs to move to these frameworks.

Activity-based models have a number of analytical advantages over conventional trip-based models. These include the following:

- Activity-based models provide a more accurate representation of travel behavior. While no model can replicate the complexities of human behavior, the activity-based approach is closer to the actual decision processes, in the following ways:
  - Travel is modeled as a demand derived from the desire to perform activities;
  - The dependencies among different trips made by the same person are considered;
  - Intrahousehold dependencies can be explicitly considered;
  - Trip chaining is considered;
  - Time-of-day choice explicitly is considered; and
  - Interactions among choices (such as mode, destination, and time-of-day) are considered much more fully.
- Activity-based models are applied at a disaggregate level to individuals, whose personal activities and travel are simulated. This greatly reduces aggregation error.
- The logic and output of activity-based models can be easier to understand for decision-makers and the public, who may find the four-step modeling process hard to understand.
- Activity-based models provide the ability to perform certain types of analyses, such as road pricing, environmental justice, and peak spreading, or to perform them more accurately.

However, there are disadvantages of activity-based modeling, relative to trip-based modeling, which include the following:

- Activity-based models are more complex;
- Activity-based models are more expensive to implement, validate, update, and maintain;
- Activity-based models often require more consultant assistance to develop;
- Activity-based model run times can be longer;
- Managing simulation error in activity-based models can result in the need for multiple model runs for each scenario;
- Hardware requirements can be greater; and
- Custom software can be required for activity-based models (although adapting some software from existing models is possible).

Because activity-based models are more complex, more expensive, and take significant time to develop, implementing an activity-based model should be included in long-term model development plans. At the same time, updating and improving the current four-step model is a valid option for near-term model enhancements, although the potential priority for development of a new activity-based model may influence the timing or deferment of such improvements. The following section presents a review of practice. This is followed by a discussion of near-term enhancements to the current model, a discussion of long-term model development, and identification of next steps.

# 2.0 Review of Practice

## 2.1 Review of Current Four-Step Model

The current TPB regional travel model performs reasonably well in representing and forecasting aggregate system- and corridor-level travel demand, but cannot fully address complex policy alternatives and traffic operation scenarios applying to strategies such as:

- Road and congestion pricing;
- Time-specific policies;
- Improvements in traffic operations and ITS deployment;
- Freight and goods movement;
- Nonmotorized travel; and
- Peak spreading and highly congested networks.

In order to improve the current trip-based regional travel model, various near-term enhancements should be considered, such as updating every model component using the new 2008 household survey data, replacing gravity models with destination choice models, adding new components such as time-of-day choice models, and developing special generator models to capture airport travel, special events and visitor travel. All of these potential improvements are described in more detail in Section 3.

## 2.2 Review of Activity-Based Models

CS reviewed the documentation of nine urban activity-based models in North America. Information collected as part of projects for the Florida Department of Transportation (DOT) and Michigan DOT which will be presented at the 2009 Annual Meeting of the Transportation Research Board (Rossi et al., 2009) have been used. The models reviewed include the following:

1. **San Francisco County Transportation Authority (SFCTA) Model –** Activity-based model for San Francisco County completed in 2001;
2. **New York Model –** Activity-based model for the New York metropolitan area completed in 2002;

3. **Columbus Model –** Activity-based model for the Columbus, Ohio urban area completed in 2005;
4. **Sacramento Model –** Activity-based model for the Sacramento urban area completed in 2007;
5. **Lake Tahoe Model –** Activity-based model for the Lake Tahoe urban area completed in 2007;
6. **Atlanta Model –** Activity-based model for the Atlanta urban area currently under development;
7. **Portland Model –** New activity-based model for the Portland urban area currently under development;
8. **Denver Model –** Activity-based model for the Denver urban area currently under development; and
9. **Metropolitan Transportation Council (MTC) Model –** Activity-based model for the entire San Francisco Bay urban area, currently under development.

Table 1 provides some general information on these nine models. Table 2 summarizes the technical details of the models as obtained from the model documentation. The models are arranged in these tables from left to right and approximately in the order in which they were completed (or are expected to be completed).

## Table 1. General Model Information

| | SFCTA | New York | Columbus | Sacramento | Lake Tahoe | Atlanta | Portland | Denver | San Francisco (MTC) |
|---|---|---|---|---|---|---|---|---|---|
| Year Completed | 2001 | 2002 | 2005 | 2007 | 2007 | 2008 (est.) | 2008 (est.) | 2008 (est.) | 2009 (est.) |
| Base Year | 2000 | 1996 | 2000 | 2005 | 2000 | 2000 | | 2005 | 2000 |
| Forecast Year | | 2020 | 2030 | 2035 | | 2030 | | 2035 | 2030, 2050 |
| Survey Data Year | 1990 | 1998 | 1999 | 2000 | | 2001 | 1994 | 1997 | 2000 |
| Number of Households in Survey | 1,300 | 11,000 | 5,600 | 3,900 | 1,220 | 8,100 | 6,000 | 4,900 | 15,000 |
| Zones (Approximate) | 1,700<br>(750 in SF) | 3,600 | 1,800 | 1,500 | 289 | 2,000 | 2,000 | 2,800 | 1,454 |
| Base-Year Population | 750,000<br>(SF only) | 20,000,000 | 1,500,000 | 2,000,000 | 63,448 | 4,700,000 | 1,600,000 | | 6,783,760 |

Note: Missing values indicate information not available from documentation or interview.

## Table 2. Model Technical Information

| | **SFCTA** | **New York** | **Columbus** | **Sacramento** | **Lake Tahoe** | **Atlanta** | **Portland** | **Denver** | **San Francisco (MTC)** |
|---|---|---|---|---|---|---|---|---|---|
| Microsimulation of Individuals? | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Model Types | MNL/NL | MNL/NL | MNL/NL | MNL/NL | MNL/NL | MNL/NL | Markov process/ MNL/NL | MNL/NL | MNL/NL |
| Number of Activity Purposes | 3 | 6 | 7 | 7 | | 8 | 7 | 7 | 11 |
| Population Synthesizer Variables | I/P/W/A | I/P/W/ NWA/C | NWA(2)/ WA(2)/C(3) | I/P/W/A | I/P/W | I/P/W/A | | I/P/W/A | I/P/W/A/C/D /R |
| Long-Term Choices | AO | AO | AO | WL/SL/AO | AO | WL/UL/ SL/AO | | WL/SL/AO | HAT/WH/WL /SL/AO/PC/ |
| Household/Person-Level Models | DAP | DAP | DAP | DAP/#T | DAP | DAP/AA/# MT | | DAP | DAP/AA/#MT |
| Tour-Level Models (in Order of Application) | ToD, C, DC, MC | PMC, DC, MC, #S, ToD | JTF, #DT, DC, ToD, MC | DC, ToD, MC, #S | JTF, #DT, DC, ToD, MC | EC, JTF, PJT, AMT, DMT, #DT-S, #WS, DC, ToD, MC | | #WS, DC, MC, ToD, #S | EC, JTF, PJT, AMT, DMT, #DT-S, #WS, DC, ToD, MC |
| Trip-Level Models | DC/MC | DC/ToD | DC/MC | DC/MC/ToD | DC/MC | DC/ToD/MC | | DC/MC/ToD | DC/MC |
| Other Models | Visitor | Freight/ext | CV/ext | | Visitor/ external | | | CV/airport | |
| Location Choice Level | Zone | Zone | Zone | Parcel | Zone | Zone | Zone | Zone | Zone |
| Time Period Resolution for Model | 5 aggregate periods | 4 aggregate periods | 19 (hours, mainly) | 30 minutes | 1 hour | 1 hour | | 1 hour | 1 hour |
| Use of Time Windows | No | No | Yes | Yes | Yes | Yes | | Yes | Yes |

Key to abbreviations located on last page of table.

Note: Missing values indicate information not available from documentation or interview.

## Table 2. Model Technical Information (continued)

| | SFCTA | New York | Columbus | Sacramento | Lake Tahoe | Atlanta | Portland | Denver | San Francisco (MTC) |
|---|---|---|---|---|---|---|---|---|---|
| All Stops Allocated in DAP Model | No (classification) | No | No | No | No | No | | No | No |
| Household Interactions | No | Limited | Yes | No | Limited | Yes | Yes | No | Yes |
| Modes: Nonmotorized | | (1-PMC model) | 1 | 2 | 1 | | | 2 | 2 |
| Modes: Auto | | 4 | 2 | 3 | 2 | | | 3 | 10 |
| Modes: Transit-Walk Access | | 2 | 1 | 1 | 1 | | | 1 | 5 |
| Modes: Transit-Auto Access | | 2 | 1 | 1 | 1 | | | 1 | 10 |
| Modes: Other | | School bus, taxi | School bus | School bus | School bus | | | School bus | |
| Highway Assignment | SUE | SUE | SUE | SUE | Capacity restraint | Under development | | SUE | |
| Assignment/ Skim Time Periods | 5 | 4 | 4 | 4 | 4 | 4 | | 4/8 | 5 |
| Feedback | | Yes | | Yes | | | Yes | Yes | Yes |

Key to abbreviations located on last page of table.

Note: Missing values indicate information not available from documentation or interview.

## Table 2. Model Technical Information (continued)

*Key*

| **Model Type** | |
|---|---|
| MNL | Multinomial logit |
| NL | Nested logit |

| **Population Synthesizer Variables** | |
|---|---|
| I | Income |
| P | Persons per household |
| W | Workers per household |
| A | Age of head of household |
| NWA | Nonworking adults |
| C | Children |
| D | Dwelling type |
| R | Ethnicity |

| **Long-Term Choices** | |
|---|---|
| WL | (Usual) work location |
| UL | (Usual) university location |
| SL | (Usual) school location |
| AO | Auto ownership |
| WH | Work at home choice |
| PC | Parking cost |
| HAT | Household access to transit |

| **Person/Tour/Trip-Level Models** | |
|---|---|
| DAP | Daily activity pattern |
| AA | Activity allocation |
| C | Classification (see SF model summary) |
| #T | Number of tours |
| #MT | Number of maintenance tours |
| #DT | Number of discretionary tours |
| EC | Escorting children to school |
| JTF | Joint tour frequency |
| PJT | Person participation in joint tours |
| AMT | Allocation of maintenance tasks |
| DMT | Distribution of maintenance tasks by mandatory tours |
| #S | Number of stops |
| #DT-S | Number of discretionary tours/stops |
| #WS | Number of work-based subtours |
| DC | Destination choice |
| MC | Mode choice |
| ToD | Time of day |
| PMC | Pre-mode choice (motorized versus nonmotorized) |

| **Highway Assignment** | |
|---|---|
| SUE | Static user equilibrium |

### General Model Structure

It should be noted that all of the activity-based models were estimated using data from a household travel/activity survey. This is the same type of survey from which conventional four-step models are estimated. While some of the surveys collected additional data, and some of the models used data from other types of surveys, the household survey is sufficient for estimation of a complete set of choice models within the activity-based framework.

In all but one of the activity-based models examined, the activities and travel for each member of the population in the modeled region individually are simulated. A synthetic population represents the region's inhabitants, and each person's activities are predicted, along with their locations and times, and the modes of transportation used between activity locations. While the ways in which the activity patterns are predicted differ somewhat, and the overall structures among the models vary, the urban models follow the general structure shown of generation of daily activity patterns, and location, time, and mode decisions made at two levels – tour and trip.

Within this general structure, the most significant variation is that the Columbus, Lake Tahoe, Atlanta, and MTC models explicitly consider interactions among household members in the daily activity pattern process, which also has implications for later models such as mode choice and time-of-day choice. The differences in the daily activity pattern models are described below.

Except for the SFCTA model (the oldest working activity-based model), all models have between five and eight activity purposes. Nearly all models have separate activity purposes for work, school, shop, social/recreation, and personal business. Some models also have a separate activity purpose for meals.

### Model Components

The models generally have the components described below.

**Population Synthesizer –** A program to develop a synthetic population and the corresponding households for the entire modeled region, generally using control totals for key variables, including the number of persons, number of workers, and income levels, and based on an existing sample of household records (such as from U.S. Census PUMS data).

**Long-Term Choice Models –** There are two long-term choice models found in all of the activity-based models:

1. **Automobile Ownership (Vehicle Availability) Model –** A multinomial logit model that predicts the number of autos owned by a household based on characteristics such as the number of persons, number of workers, and income level; transportation accessibility; and area characteristics such as development density near the home location.

2. **Regular Workplace Location Model –** A multinomial logit model, generally with all zones as the choice set, that predicts the location of the regular workplace for each

worker. Inputs include worker characteristics and transportation level of service from the home location.

**Daily Activity Pattern Models –** The daily activity pattern modeling process includes the prediction of the following for each simulated individual:

- The sequence of activities performed during the day, with their purposes identified; these activities may include both primary activities of tours and activities performed on the way to or from the primary activities.
- The tours associated with the activities.
- The number of intermediate stops associated with the activities (in many models limited to one in each direction on the tour).
- The number of subtours (of work tours only in most cases) and the stops associated with them.

The daily activity pattern modeling process is probably the area that varies the most among activity-based models examined. Perhaps the most significant variation is that in some models, the interactions among household members are considered, including activities performed jointly by more than one household member and the need to pick up or drop off other household members performing activities away from home.

In the Columbus, Lake Tahoe, Atlanta, and MTC models, the “mandatory” activities (work and school) are modeled first, including tour-level destination, mode, and time-of-day choice. Next, joint tours (among two or more household members) are modeled, followed by maintenance (e.g., shopping) and discretionary tours. Finally, the intermediate activities (stops) are modeled. This structure differs from those used in other areas in that all tour choices (destination, mode, and time-of-day) are modeled for each tour type (mandatory, joint, maintenance, discretionary) before modeling the next tour type. Notably, the tours of higher-priority types are scheduled, with the time periods used unavailable for subsequently modeled tours.

The SFCTA, Sacramento, and Denver models do not consider any household interactions. The Portland model has unique methods for dealing with household interactions.

**Tour-Level Models (Primary Activity) –** The tour-level models include:

- **Destination Choice –** A multinomial logit model that predicts the location of the primary activity of a tour, based on transportation level of service from home, person and household characteristics, and area characteristics.
- **Mode Choice –** A nested or multinomial logit model that predicts the primary mode of each tour, based on transportation level of service from home, person and household characteristics, and area characteristics. Mode definitions are similar to those used in conventional trip-based models, with rules used to define the primary mode

for mixed-mode tours. Nonmotorized travel is included in all of the models, in some cases as two separate modes – walk and bicycle.

- **Time-of-Day Choice –** Usually a multinomial logit model that predicts the time of the primary activity of a tour, based on transportation level of service from home, person and household characteristics, and area characteristics. The time is represented by the starting and ending time of the activity, and so the activity duration also is modeled. With the home and primary activity locations known, the travel-time information can be used to determine the actual departure times from and arrival times to home although models of the intermediate stops, generally applied later, can further affect these times.

The tour-level time-of-day choice decision occurs in different places in the various models. For example, it occurs before destination and mode choice in the SFCTA models, between destination and mode choice in the Columbus, Sacramento, and Atlanta models, and after destination and mode choice in the New York and Denver models. There is no documented evidence to suggest that one particular placement of time-of-day choice is more beneficial than another. However, the placement of the time-of-day model affects how the travel-time skims are used within the models. If time-of-day precedes mode choice, then it may reasonably be assumed that the mode choice model will take advantage of the additional information, which in turn requires that multiple skim files be developed that reflect multiple time periods. Conversely, if mode choice precedes time-of-day, then typically only peak and off-peak skims would be generated and used in the mode choice models.

The SFCTA model uses five aggregate time periods for time-of-day choice; the more recent models use hour- or half-hour-long periods. However, shorter periods are aggregated to a smaller number of longer periods for trip assignment.

**Trip-Level Models (Intermediate Stops) –** The trip-level models include:

- **Destination Choice –** Usually, a multinomial logit model that predicts the location of the intermediate stops on a tour, based on transportation level of service, person and household characteristics, and area characteristics.

- **Mode Choice –** A nested or multinomial logit model that predicts the primary mode of each tour, based on transportation level of service from home, person and household characteristics, and area characteristics. Mode definitions are similar to those used in the tour-level mode choice models.

- **Time-of-Day Choice –** A model to determine the times of intermediate stops on the way to or from the primary activity.

**Trip Assignment –** Because each individual's activities and travel are simulated, activity-based modeling lends itself well to using a traffic microsimulation process. To date, however, all of the models examined used traditional static equilibrium highway assignment procedures that are the same as those used in conventional travel models. This requires conversion of the daily activity pattern data to vehicle trip tables.

Transit assignment in the activity-based models examined is also performed using conventional methods and requires conversion of the daily activity pattern data to transit person trip tables.

### Model Development Process

Based on Rossi et al. (2009) along with other information collected for this project, Table 3 was created. This table provides information about the nine models used by U.S. agencies on:

- The model implementation process, including development times and costs, data and software used, and consultant and agency responsibilities; and
- The model execution process, including software and hardware configurations, run times, and identification of who runs or will run the models.

**Model Development Process –** The model development time for those agencies who reported it ranged from 1.5 to 8 years, with typical times in the 2- to 3-year range.

Consultants were used to estimate models in almost all cases. The public agencies who eventually maintain the models always participate in data development and sometimes in model validation as well.

Most models were developed using local household activity travel surveys. The Lake Tahoe model was transferred from Columbus. Some models also made use of transit on-board, external, and other types of surveys.

Consultant costs for model development and validation have been in the $600,000 to $800,000 range. The Atlanta model cost is a bit higher, possibly because the process was spread out over eight years. It also is known that the New York model costs were outside this range although no specific estimate was available. The Portland model, which is being developed mainly in-house, is expected to have consultant costs of about $200,000. Consultant costs do not include data collection and in-house staff costs. In-house staff costs will vary depending on the involvement of the staff in model development and validation.

## Table 3. Model Implementation Information

| | SFCTA | New York | Columbus | Sacramento | Lake Tahoe |
|---|---|---|---|---|---|
| Total Model Development Time (Months) | 18 | | 42 | 24 | |
| Model Estimation Software | ALOGIT | ALOGIT | | ALOGIT | |
| Model Application Software (Network/Matrix) | Cube | TransCAD | Cube/Voyager | Cube/Voyager | TransCAD |
| Model Application Custom Program Language | C++/Java | C/C++/ FORTRAN | Java | Delphi/Pascal | |
| Hardware (PC) | 1 (now 5) | 8 | 5 | 1 | |
| Hardware (Processors/PC) | 1 | 2 | 2 | 2 | |
| Run Time (Hours) | 24 (now 10) | | 31-41 | 20-26 | |
| HD Space Required | 7 GB | | | 9 GB | |
| Model Estimation Work | Consultant | Consultant | Consultant | Consultant | Consultant (used MORPC) |
| Data Development Work (Networks, Socioeconomic/Land Use) | Agency | | Agency/ Consultant | Agency | |
| Validation Work | Consultant | Consultant | Agency/Consultant | Agency/Consultant | |
| Surveys Used | HH/SP/V | HH/Ext | HH/TOB/Ext | HH/TOB | HH (from MORPC)/Visitor |
| Other Data Used | Census | | | Census/ Parcel Database | Census |
| Consultant | CS with MAB/PB | PB/AECOM/ UI/CS | PB/MAB | MAB/JLB/DKS | PB |
| Cost – Data Collection | (Data from MTC) | | $550,000 | $400,000 | |
| Cost – Model Development/ Validation – Consultant | $700,000 | | $650,000 | $580,000 | |
| Cost – Model Development/ Validation – Agency | | | $350,000 | | |
| Monte Carlo Simulation Stabilization | 6 runs/averaged | | Some fixed | Fixed seeds | |
| Run by MPO/DOT | Yes | Yes | Yes | Yes | Yes |
| Run by Outside Agencies | No | | Yes (ODOT) | No | No |
| Run by Outside Consultants | No | Yes | No | No | No |

Key to abbreviations located on last page of table.

Note: Missing values indicate information not available from documentation or interview.

## Table 3. Model Implementation Information (continued)

| | **Atlanta** | **Portland** | **Denver** | **San Francisco (Regional)** |
|---|---|---|---|---|
| Total Model Development Time (Months) | 100 (est.) | 24 (est.) | 30 (est.) | 24 (est.) |
| Model Estimation Software | ALOGIT | | ALOGIT | ELM |
| Model Application Software (Network/Matrix) | Cube/Voyager | EMME/2, VISUM | TransCAD | Cube/Voyager plus Cube Cluster |
| Model Application Custom Program Language | Java | Python | C# | |
| Hardware (PC) | 1 (expected) | 6 | 1 | 1 Server (dual)/ 4 Workers (dual) |
| Hardware (Processors/PC) | 1 (expected) | 2 | 2 | |
| Run Time (Hours) | Under development | Under development | Under development | |
| HD Space Required | 10 GB (est.) | Under development | Under development | |
| Model Estimation Work | Consultant | Agency | Agency/Consultant | Agency/Consultant |
| Data Development Work (Networks, Socioeconomic/Land Use) | Agency/Consultant | Agency | Agency/Consultant | Agency |
| Validation Work | Agency/Consultant | Agency | Agency/Consultant | Agency |
| Surveys Used | HH/TOB | HH | HH/Ext | HH |
| Other Data Used | Census | | Census | Census |
| Consultant | PB/JLB/MAB/ PBS&J/AECOM | PSU/PTV | CS/MAB/JLB | PB/MAB |
| Cost – Data Collection | $1,000,000 | $1,200,000 (future) | | |
| Cost – Model Development/ Validation – Consultant | $1,200,000 | $200,000 | $800,000 | |
| Cost – Model Development/ Validation – Agency | $500,000 | | | |
| Monte Carlo Simulation Stabilization | Under discussion | Under development | Under discussion | |
| Run by MPO/DOT | Yes | Yes | Yes | Yes |
| Run by Outside Agencies | No | No | Yes | No |
| Run by Outside Consultants | No | No | Yes | No |

Key to abbreviations located on last page of table.

Note: Missing values indicate information not available from documentation or interview.

## Table 3. Model Implementation Information (continued)

*Key*

| Surveys Used | | Consultant | |
|---|---|---|---|
| HH | Household | CS | Cambridge Systematics, Inc. |
| V | Visitor | MAB | Mark Bradley |
| Ext | External | JLB | John Bowman |
| TOB | Transit On-Board | PB | Parsons Brinckerhoff |
| SP | Stated-Preference | DKS | DKS Associates |
| | | UI | Urbitran |
| | | PBS&J | Post, Buckley, Schuh, and Jernigan |
| | | PSU | Portland State University |
| | | PTV | PTV America |

**Model Execution –** A variety of software packages have been used for model application. Custom programs for models currently under development are being written in several languages, including C#, Java, and Python, although C++ was often used in the past.

The SFCTA model originally was designed to run on a single processor, but SFCTA has moved to a distributed computing environment to improve the efficiency of the model runs. The largest models, New York and Ohio, used over 15 processors while most of the remaining models used (or are expected to use) 10 to 12.

The run times are available only for those four models that were in use at the time of the interviews conducted for the Michigan process (2007). (New York also was in use, but the agency was not interviewed.) The SFCTA model took over a day to run when first implemented in 2001, but it now runs in about 10 hours, thanks in part to the move to distributed processing. The Sacramento and Columbus models take one to two days to run. From this small sample, it appears that agencies are targeting about one day for a reasonable model run time, and some have used multiple processors to achieve this.

Only three agencies were able to estimate the amount of hard drive space for a single model run. The range is from 7 to 10 GB.

Most of the models are not run by agencies outside of the agency that maintains the model. Outside consultants run the New York model, and it is planned that outside consultants and agencies will run the Denver model.

### *Policy/Planning Analysis*

Activity-based models that already are in use have been proven to be useful for the analyses needed for transportation planning. The models have been successfully used for a variety of analyses, including long-range transportation plans, highway and transit project evaluation, FTA New Starts project evaluation, air quality conformity analysis, environmental justice analyses, and road pricing studies.

There is insufficient information to perform comparisons among how the various activity-based models are used to perform policy and planning analyses. There is little that can be said about how the specific differences among the models, such as the explicit modeling of household interactions, the placement of time-of-day choice, etc., will affect the accuracy of the model in informing specific analyses. The information presented below, therefore, includes differences only between aggregate trip-based (e.g., four-step) and disaggregate activity-based models and not among the various disaggregate models examined.

Analyses that would benefit from the use of activity-based models include the following:

- **Toll Feasibility Studies –** A key input into road pricing analysis is the value of time saved by using the priced facility. The best that can be done with conventional models is to assume fixed values of time by market segment. This obvious oversimplification can be mitigated in a disaggregate model by simulating a value of time for each traveler based on his/her characteristics and distribution of values of time.

- **High-Occupancy Vehicle (HOV) Lane Studies –** Trip chaining and intrahousehold interactions can have a significant effect on the decision to carpool and automobile occupancy in general.

- **New Starts/Small Starts Analyses, System-Level Transit Ridership by Mode, and Transit Operations –** Transit modeling can benefit from the activity-based approach in a number of ways. For example, transit access distances can be simulated rather than using aggregate "walk percentages" to determine walk access to transit at the zone level. Also, the effects of trip chaining and the need to perform other activities (such as pickup/drop-off activities on the way to or from work) on mode choice can be considered in activity-based models. In addition, it is impossible to determine the effects of transportation projects on specific subgroups of the population (for example, low-income persons) in aggregate models. It is necessary to microsimulate individuals and save the information on travelers to determine how these effects are allocated to the population.

- **Congestion Management Systems –** The condition of the transportation system (i.e., levels of congestion) on travel behavior is modeled more accurately when the effects on the entire daily activity pattern are considered than when they are not (as in four-step models). The more disaggregate time periods used in the later models should produce greater accuracy in this regard.

- **Escorting Children to School –** Activity-based models can capture the interdependency between the needs of children to be dropped off at school and a parent's departure time for work. Explicitly modeling this interaction will allow for a better understanding of children's school travel for Safe Routes to School evaluation, and will capture the inflexibility of work departure times due to escorting responsibilities. This will have an affect on the impact of peak spreading and work flexibility strategies, as well as HOV lane studies.

- **Highway Operations –** This type of analysis may require traffic microsimulation, which is consistent with the disaggregate approach used in activity-based models.

- **Time-of-Day Assignment –** When considered at all, time-of-day analysis in conventional models is done using fixed factors, making it impossible to consider peak spreading or to properly analyze such things as congestion pricing or time-variable tolls. Activity-based models explicitly consider time-of-day choice and can consider variables based on congestion and variable costs.

- **Air Quality Conformity Determinations –** Significant postprocessing of results of models that consider only aggregated time periods is needed to produce inputs for air quality analysis. Those models that determine time of day at an hourly level or less can provide more accurate information on temporal variations in speeds and traffic volumes. It should be noted, however, that all of the models described here still aggregate to longer periods for traffic assignment, and so further disaggregation would be required to produce these more accurate outputs.

- **Determine Impact of Proposed Developments and Impact Fee Calculations –** Any travel model could use variables reflecting development types in its choice models. All of the activity-based models reviewed have variables reflecting development patterns at some level.

- **Bicycle and Pedestrian Trips –** Nonmotorized travel is considered in all activity-based models.

- **Emergency Evacuation Modeling Support –** This can depend on the specific locations of individuals at the time of evacuation. Only activity-based models track the activity patterns of individuals.

- **Integrated Land Use Model –** While an activity-based model is not required to use an integrated land use-transportation model, the richness of the set of variables that can be considered in activity-based models enhances the effectiveness of integrated modeling. Some activity-based models (e.g., TASHA) successfully have been integrated with land use models.

- **Campus Master Plans –** Travel by students and others associated with universities generally are not well modeled by conventional means. However, to model them accurately by any means requires data on student travel patterns, which are not always well covered in conventional household surveys.

- **Incorporate Ability to Test Impact of Gasoline Prices –** While much more information than exists now is needed to be able to evaluate the effects of significant gasoline price changes by any means, the activity-based approach lends itself to consideration of more of the choices faced by households and travelers (for example, vehicle ownership and allocation, trip chaining, and cost effects on choices other than mode choice). Sensitivity to price is more accurately considered in activity-based models because the models are applied to individuals whose activities and travel are simulated, rather than assigning the same average characteristics such as values of time to large segments of the population.

## ■ 3.0 Near-Term Enhancements to Current Model

This section describes potential near-term enhancements to the current TPB model. The section is organized into six sections: Overall Enhancements to Current Model, Destination Choice Models, Time-of-Day Choice Models, Value of Time Considerations, Assignment Models, and Special Generator Models.

### 3.1 Overall Enhancements to Current Model

As a routine model updating exercise, every large MPO conducts household surveys periodically. The 2008 household survey that TPB has conducted will be a valuable source for the next model update. The current practice used by TPB in trip generation to estimate trip productions and attractions for both motorized and non-motorized activity is consistent with methodologies used by many MPOs. With the new survey data, the trip generation model can be fine tuned as follows:

- Review and summarize findings of the 2008 household trip generation and attraction rates at the subregional level;
- Consider enhancing the application of year 2000 PUMS data by incorporating more detailed zonal data found in the 2000 CTPP;
- Determine the reasonableness of the current trip generation rates relative to procedures used by similar size MPOs, and estimate new generation rates from the 2008 household survey by TAZ or district;

The model improvement tasks for trip distribution suggest focus on vehicular demand in all the major corridors. The work trip movements from PUMS can be analyzed in addition to the new household survey. The highway network speeds should be validated to observed speeds as they serve as a key input to trip distribution. The following updates to distribution can be done using the new household survey data:

- Review the intradistrict versus interdistrict trip movements against the household and Census datasets. Test the option of using two sets of friction factor curves, one for short trips and another for long trips.
- Validate county-level average trip lengths and times for all trip types to the 2008 household survey and the 2000 work trip data from the Census.
- Validate screenlines by time period to evaluate the trip distribution and assignment validation. Adjust networks along with trip generation and distribution parameters to improve screenline validation.

Improvements to the TPB mode choice models currently underway should be done to meet the FTA guidelines on forecasting for two reasons: 1) these guidelines represent conservative standard practice and, therefore, address current concerns about the mode choice model; and 2) the models could then be used to evaluate New Starts projects. The objective in applying these guidelines is primarily to improve the mode choice model, but these guidelines also apply to highway and transit network and path building. The new 2008 household survey data should be used to update and re-calibrate the mode choice model parameters.

## 3.2 Destination Choice Models

Destination choice models perform the same general function that trip distribution models, such as the gravity model, do in the traditional four-step modeling process. The estimation of these models is very similar to other choice models (such as mode choice) where all destination TAZs form the choice set and are specified as alternatives. These are usually specified as multinomial logit models and are estimated by trip purpose. The explanatory variables typically included are distance, mode choice logsums, region and area type, party size, demographics, and employment and household characteristics. Every zone is a potential destination choice, and so the utilities for every zone are computed at the origin-destination pair level and the destination choice shares are also computed at the origin-destination pair level. So, the destination choice models determine not only the trip interchanges but also the total attractions for each zone.

The calibration and validation of these models will be very similar to that of gravity models, where the modeled trip length frequency distributions are compared against the observed survey data.

Though there is little doubt that destination choice models are superior to gravity models, the value of migration may be limited if an activity-based model is planned within a few years because re-estimation would be necessary.

## 3.3 Time-of-Day Choice Models

In a recent forum on road pricing,[1] attendees identified and discussed limitations with current travel demand forecasting approaches for pricing studies. In addition, CS recently completed a paper on the limitations of studies used to advance toll projects[2] and on the opinions of Washington State's community leaders.[3] Based on these sources and recent Cambridge Systematics (CS) experience in developing forecasting models for toll projects, one of the key issues of primary importance to improving existing travel models for pricing studies is the lack of temporal detail and behavioral choice for time-of-day models.

The approach CS has been developing to advance four-step travel models for the purposes of pricing studies involves focusing on estimating and applying time-of-day choice models in existing four-step models. CS has been involved in the development and application of these methods for trip-based models in Minnesota and Washington, as well as for activity-based models in San Francisco.

Capturing the variations in travel by time of day is essential to predicting transportation system performance and air quality impacts of the transportation sector. A vast amount of transportation research has been conducted to study travel demand by time of day. Much of this research has been limited to observing trends in service usage, such as

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[1] Expert Forum on Road Pricing, sponsored by Federal Highway Administration, Volpe Center, held on November 14-15, 2005 in Arlington, Virginia.

[2] Cambridge Systematics, *Washington State Comprehensive Toll Study Interim Report, Background Paper No. 6: Limitations of Studies used to Advance Toll Projects,* prepared for the Washington State Transportation Commission, November 2005.

[3] Cambridge Systematics, *Washington State Comprehensive Toll Study Interim Report, Background Paper No. 2: Ascertainment Interviews: Opinion of Washington's Community Leaders,* prepared for the Washington State Transportation Commission, November 2005.

vehicular volumes and the number of person trips. While important to understanding past and present usage patterns, these types of studies are less valuable for predicting future travel by time of day given changes in transportation service availability, quality, and policy. Possibly the behavior least accounted for in travel forecasting is "peak spreading" (i.e., persons rescheduling their travel from daily periods of high demand to the portions of the day where travel takes less time and is more reliable). Travel surveys and other monitoring activities have documented the correlation between decreasing service quality (congestion) and longer peak periods. Also, many planning agencies need to test the effectiveness of policy initiatives specifically targeted at shifting travel demand to off-peak periods.

The time-of-day choice model can provide sensitivity to traveler's temporal decisions with respect to sociodemographic, travel conditions, and cost of travel. This sensitivity is needed to effectively evaluate congestion pricing strategies and improve forecasting results. Therefore, the inclusion of more temporal details or time periods can make such models more sensitive to congestion pricing (which can vary greatly over the peak period).

Most prior time-of-day choice modeling studies consider time as a discrete variable. That is, the various time choices are represented by several temporally contiguous discrete time periods such as morning peak period, off-peak period and evening peak period. There are several drawbacks of using such an approach to model time-of-day choice.[4] The use of discrete time periods requires a pre-determined partitioning of the day into time intervals, the characteristics of which may or may not be the same in the future. This might preclude the analyses of potential future congestion pricing strategies during time periods which are smaller than those used in the base year. Also, the discrete choice structure considers the time points near the boundaries of intervals as belonging to one or the other of the aggregate time periods, but in reality, two closely spaced time points on either side of a discrete interval boundary are likely to be perceived as being similar rather than as distinct alternatives. So, either many finer discrete time intervals have to be specified to obtain a reasonable time resolution, which might not be very practical as this would involve estimating many parameters, or a distinction would need to be made between adjacent discrete time periods.

CS performed research project on time-of-day models for the Federal Highway Administration (FHWA) that resulted in two methodologies for time-of-day choice models: one that could be used for trip-based models and another that could be used for activity-based models. These methodologies were tested and validated in case studies in Denver and San Francisco. The Denver time-of-day choice method estimated trips by time of day for half-hour periods. The application of the resulting model showed a modest amount of peak spreading resulting from the implementation of the period-based tolls. The San Francisco tour-based time-of-day modeling method also estimated trips by time

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[4] Bhat, C. R., and J. L. Steed, 2002, A Continuous-time Model of Departure Time Choice for Urban Shopping Trips, *Transportation Research Part B* (36), pp. 207-224.

of day for half-hour periods and was applied to a pricing scenario for downtown San Francisco.

For the Washington State DOT, CS updated an existing set of time-of-day choice models by dividing the five main periods (morning peak, midday, evening peak, evening, and night) into 30-minute subperiods, in order to model peak-spreading behavior.[5] In addition to automobile travel time variations between periods, the model was also structured in such a way that it would be sensitive to automobile travel cost differences between periods, for instance to emulate time-of-day-specific congestion pricing. The new time-of-day choice models were estimated using multinomial logit structures for eight trip purpose/direction combinations, using a new set of 32 choice alternatives.

These models are typically estimated using time use and travel information from traditional household surveys, and the variables that are usually found to influence travelers' time-of-day choice are:

- **Sociodemographic** – Income and household size.
- **Land Use/Accessibility** – Number of jobs that can be accessible by automobile within a certain range of distance (5-10 miles), and retail or service employment accessible by automobile within a certain range of time (10-15 minutes).
- **Origin-Destination Pair/Level of Service** – Automobile in-vehicle generalized cost (in minutes), delay (in minutes), bridge dummy variable (if relevant to the study area), and shared ride dummy variable.

Time-of-day models are typically implemented after the mode choice step but before the assignment step so that the changes due to the feedback process for travel times to trip distribution and mode choice are captured prior to the time-of-day choice model. After the final iteration, the trips in each finer time slice (e.g., 30-minute time periods) are aggregated back to the aggregate time periods (e.g., morning peak, midday, evening peak, etc.) for evaluation of performance on the system.

The calibration and subsequent validation of the time-of-day choice model is typically done in a two-stage process:

- **Stage 1** – Calibrate and validate against weighted survey data by purpose, mode of travel, time-of-day, direction, and by income group. This is to ensure that purpose and directions are calibrated correctly by mode of travel. The process involved adjusting the alternative specific constants until the actual differences in the time-of-day shares are within +/-0.02

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[5] Kuppam, A. R., M. L. Outwater, M. Bradley, L. Blain, R. Tung, and S. Yan (2005) Application of Time-of-Day Choice Models Using EMME/2 – Washington State DOT Congestion Relief Analysis. Presented at 19th International EMME/2 User's Group Conference, Seattle, Washington, October 19-21, 2005.

- **Stage 2** – Calibrate and validate against observed traffic counts after assignment by time-of-day. The second stage will involve calibrating and validating the time-of-day choice model against the observed vehicle miles traveled (VMT) based on traffic counts by time period to ensure that the modeled VMT by time-of-day is within +/- 10 percent. In this stage, the alternative specific constants by purpose and direction will be adjusted uniformly so that the underlying relationship between purpose and direction from Stage 1 are retained.

Cambridge Systematics recognizes that there are traffic count data limitations in the TPB modeled region that may make immediate development and validation of time-of-day choice models difficult, but addressing these limitations should be among the near-term regional data improvement priorities of its member governments. Enhanced time-of-day count data could support not only the advanced modeling but also inform many other types of analyses and provide much richer data for validation. Prioritization of the development of a time-of-day choice model for the existing four-step model depends somewhat on the anticipated timing for development of an activity-based model framework because the time-of-day choice model would need to be replaced as part of the migration to an activity-based model framework and the resources required for its development might then have been better expended in other areas. In addition, there are fewer success stories of implementation of time-of-day choice models within the four-step model framework as compared with success stories of destination choice model implementation within such a framework.

## 3.4 Value of Time Considerations

Value of time considerations are a possible area to look at for near term model improvement, especially as the component models are revisited to incorporate the 2008 household interview survey. The estimation and application of value of time considerations in travel demand forecasting models is another most-often cited problem with these models for evaluating pricing projects. There are a number of issues related to considering the value of time that present challenges in the travel demand forecasting process:

- How to distribute values of time across individual travelers, i.e., with different income levels?

- How to distribute values of time across different trips, i.e., with different purposes and modes?

- How to distribute values of time across different destinations, i.e., trips to the airport?

- How to distribute values of time across different vehicle types, i.e., with different vehicle classes?

- How to distribute values of time based on what type of goods are being carried for truck trips?

- How to distribute values of time for different types of congestion, i.e., recurring and nonrecurring congestion, such as accidents?

In a fully disaggregate travel demand forecasting system, values of time (or distributions of values of travel time) can be used based on the traveler, the trip, the vehicle type, and the goods being carried and could remain consistent throughout the forecasting process, eliminating the application-related issues surrounding the values of time. For aggregate trip-based models, such as the TPB travel model, incorporating values of time for individual travelers, trips, and vehicles is impossible, but it is possible to identify specific categories of travelers, trips, and vehicles and apply values of time for these categories. This can be an effective means of distributing values of time within the forecasting system, but to make it fully effective requires using consistent market segmentation throughout the model chain (i.e., to assess values of time by income group, one must represent income group within each model component, including trip assignment).

CS has completed studies in Minnesota and Washington State where model improvements were assessed and implemented specifically to address value of time considerations. The model developed for Washington State explicitly included value of time in the mode choice model using time and cost coefficients for each type of traveler. In addition to income-based segmentation, other market segmentation dimensions with potential value of time considerations, such as trip distance, time of day, gender, and age, were tested. As it turned out, the effects of these other dimensions were difficult to incorporate into the model stream and were found to have marginal impact on the models.

In Minnesota, toll mode constants were developed using information from models in other locales. CS calculated the ratio of toll-alternative-specific constants to highway travel time coefficients for different market segments in the reference models based on age, gender, income level, education level, and trip purposes. Assumptions about the distribution of trip and traveler characteristics by purpose (including household income, gender, educational attainment, and age) for the Twin Cities population were made based on reviewing parameters from elsewhere. Free highway and toll mode constants for the Twin Cities were developed along with some adjustments in average equivalent times across market segments to enable explorations of new variable priced facilities.

As discussed above, value of time considerations extend to route choice and trip assignment, particularly when exploring issues of priced facilities and non-recurring congestion. Aggregate assignment methodologies only allow for assignment of trips by category or class rather than by individual vehicle. As the number of categories needed to adequately represent the values of time of individual travelers are increased, it becomes clear that disaggregate assignments (microsimulation or a dynamic traffic assignment process) would greatly improve the capability to accurately represent value of time considerations. This, however, is a long-term enhancement, and one that none of the currently-implemented disaggregate models in use by major MPOs includes in production.

## 3.5 Assignment Models

The assignment model should be updated whenever any other model component is updated or improved based on new observed data. Also, the assignment models should be recalibrated to match the latest traffic count data along screenlines, major corridors, and against the HPMS-based VMT estimates. In order to analyze new policies such as travel demand management strategies and variable pricing, trip purpose and income group stratifications are more desirable to be incorporated into the multiclass assignment procedures. In a recent project for Washington State DOT, CS developed an assignment model that included four classes of drive-alone home-based work trips, based on income quartiles. This was essential to see the impact of different ranges of tolls on different income groups. Additional modes such as shared ride, vanpool, and trucks (by axle type) were also considered in the assignment model.

As discussed under the value of time section, different values of time by vehicle class, purpose, and income quartile are particularly useful for pricing studies. These values of times would need to be incorporated into the assignment model.

In addition to using multiclass assignments, the model also could be improved based on calibration of volume-delay functions by facility type. Traditional travel models have used the default Bureau of Public Roads (BPR) curve with the same set of parameters for all facility types. It is recommended that different parameters be estimated and explored for different facility types. Other functions such as conical and Akcelik functions should be also evaluated to see if they improve the assignment model.

## 3.6 Special Generator Models

### *Airport Model*

The TPB modeled region is home to three major commercial airports: Ronald Reagan Washington National Airport (DCA), Washington Dulles International Airport (IAD), and Baltimore Washington International Thurgood Marshall Airport (BWI). The annual number of passengers recorded at these three airports in 2007 was 19 million, 25 million, and 20 million, respectively. This translates approximately into about 175,000 passengers on a daily basis at these three airports combined. This results in a lot of trips to and from the airports that include drive alone, shared ride, and transit trips. If TPB decides to develop an airport model to model these trips, then this section briefly describes the data needs, model estimation, validation, and implementation of such a model within the TPB travel model system.

The purpose of the airport model is to provide an analysis capability to:

- Project the future number and distribution of air passengers, employees, meeters/greeters, service, and air freight trip ends within the region;
- Determine the allocation of these trips by mode and time of day;

- Integrate these forecasts with the regional travel model, so that the forecasts better reflect airport related trips and the airport model reflects regional development and transportation supply changes; and

- Provide analysis capabilities to study changes in airport usage patterns, including significant changes in airline operations and capacity limitations.

This analysis capability can be a component of the regional airport system planning process and can allow the airport system planning process to be integrated with the surface transportation system planning process in the region. This integration ensures that forecasts of the future distribution of air passenger traffic among TPB traffic analysis zones fully reflect the projected future travel times on the regional highway system and available transportation alternatives (such as enhanced public transportation systems), and that the resulting vehicle and passenger flows are incorporated into the corresponding traffic projections for the different elements of the regional surface transportation system.

### Data Requirements

Available data from Metropolitan Washington Airports Authority (MWAA) and Maryland Aviation Administration (MAA) would need to be compiled, reviewed, and summarized to assess the necessity to identify and assemble more data to develop an airport travel model. These data would encompass operations, passenger volumes, and usage of airport access options. Any forecast data available from the three airports would also be desired, and usual sources for these include the U.S. DOT ten percent ticket sample data, the U.S. DOT Form 41 filings data, FAA long range regional forecasts, and FAA Terminal Area Forecasts.

The design of the model needs to consider the constraints imposed by the availability of data on the existing patterns of air travel and access patterns to the airports. The key modeling design and implementation challenge will be to integrate available data as effectively and efficiently as possible. The ultimate model design would need to reflect the data integration, as well as the possibility of taking advantage of future survey data if and when they were collected.

### Model Development

The model development effort for each model component consists of assembling the required data and applying the modeling procedures. The individual model component development would rely on available survey data and information from the regional model, including zonal estimates of land use, employment, and socioeconomic characteristics, as well as highway and transit levels of service. This may require expansion upon the available data and forecasts to capture airport-specific modes and zone characteristics that are specific to the airport models, but wherever possible, the regional model variables will need to be used so that the level of effort to maintain the airport modeling capability is manageable.

For the most part, the model forms for the different components would likely be similar to other travel demand forecasting models that TPB currently maintains. Airport activity models are generally structured as growth factoring models. The trip end models are regression models and spatial interaction (gravity) models. Mode choice models are multinomial or nested logit models. Resulting trip tables are assigned to transportation networks as part of the overall regional model stream.

Individual model components would need to be validated to the extent possible using airport usage and count data, as well as other ground count and ridership data compiled by TPB. An upcoming ACRP Synthesis Project, for which Cambridge Systematics staff served on the Technical Panel, surveys airport access models in use throughout the country. This can be used to compare the airport model parameters to those of the other recent modeling efforts.

### *Special Events Model*

FTA has long recognized that conventional travel models, which deal with "average weekday" travel, are not suited to the estimation of demand for travel to and from special events such as sporting events, fairs and exhibitions, conventions, etc. The travel associated with special events can produce significant, site-specific impacts such as severe traffic congestion or transit over-crowding (and generate significant transit ridership). This might require the overlay of special events travel on the results of the regional travel model. Such analyses might include the use of techniques such as dynamic traffic assignment or microsimulation of traffic. However, the cumulative impacts of special events such as air quality impacts or additional transit revenue might be equally important for decision-making regarding future transportation investments. In this case, it might be sufficient to forecast the aggregate annual total VMT or annual transit revenue from special events.

Modeling special events is complicated by the varying nature of the events. Special events may range from semi-regular events such as sporting events or concerts to very large but infrequent events. The development of a special events model, or group of special event models, requires an understanding of the TPB modeling needs. Based on this understanding, a special events modeling process would need to be designed such that it can be readily integrated into the existing travel model and, to the extent possible, any future activity-based modeling processes. The model design will largely depend upon data availability through special event surveys for the model estimation.

In this task, a procedure to estimate the origins and destinations and mode choices for trips made by attendees to and from special events would be developed. The model would be developed using special event surveys, and the following are the two key typical model components:

- **Origin/Destination Choice** – Origins and destinations of trips to and from events of each type are determined using a gravity or logit model, or perhaps by directly applying the origins/destinations from the survey data for each type of event. The outputs are person trip tables showing origins and destinations of all special event trips in the region.

- **Mode Choice** – A logit mode choice model, estimated from special events survey data, is applied to the trip tables estimated in the destination choice component. The mode choice outputs include transit person trip tables and drive alone and shared ride vehicle trip tables.

Validation of special event models requires comparing model outputs to weighted special event survey data by appropriate market segment. The final outputs of such a model process would be estimates of attendee travel (trip tables by mode) to/from each special event handled.

### *Visitor Model*

Visitor travel is usually not explicitly modeled in regional travel models, which instead are entirely based on local household survey data and transit on-board surveys. Though these surveys potentially include some visitor trips made by non-residents of the area, such trips are usually underrepresented in the available data. The non-home based trip production models are typically estimated directly from the household survey data, which does not include visitor trips.

Visitor models have been successfully developed in other large urban areas, including San Francisco and Las Vegas, and Cambridge Systematics is currently working on developing this model for Dallas. As Washington, D.C. is an area with many tourist attractions and a steady and significant flow of visitors who do not reside within the TPB modeled region, it may be worthwhile to consider developing a visitor model. To develop such a model would require using data collected from visitor surveys. Although a trip based model would be the expected product of such an effort, consistent with other models in the region, the visitor survey data would allow consideration of the interaction of different trips made by visitors and of factors such as visitor trip purpose (e.g., business, vacation) and travel party size.

Visitor surveys are typically hotel-based surveys and information regarding travel for each visitor group is typically gathered, such as:

- The initial trip to the area from the visitors' home area, beginning at the point where the visitors enter the region (external station, airport, or bus or train station) and ending at the hotel;

- Any trips made while in the area; and

- The trip from the hotel back to the visitors' home area, ending at the point where the visitors leave the region.

The above information would need to be used to develop the visitor model such that it would represent an average weekday. In the case of multi-day visits, the beginning and ending trips would need to be scaled so that the numbers of such trips on an average weekday are accurately estimated.

The following components are typically developed to form the visitor travel model:

- **Person Trip Generation** – The number of trips per visitor, by visitor type, are estimated. The output is trip ends, both for hotels (treated as trip productions) and non-hotel locations (treated as attractions). Trips with neither end at a hotel are also estimated. Application is performed by applying the rates to estimates of occupied hotel rooms on an average weekday.

- **Destination Choice** – The origins and destinations of trips estimated in the trip generation component are determined, using a gravity or logit model. Outputs are person trip tables that can be easily integrated with the rest of the regional travel model.

- **Mode Choice** – A logit mode choice model, estimated from the survey data, is applied to the trip tables estimated in the destination choice component. The mode choice outputs then include transit person trip tables and drive alone and shared ride vehicle trip tables.

Based on the availability of data, different market segments can be considered, such as:

- Purpose of visit (business, vacation, etc.);
- Travel party size;
- Length of stay;
- Type of hotel; and
- Mode of arrival.

Validation of the visitor model is typically done by comparing the model outputs to the weighted visitor survey data by appropriate market segment. If other sources of visitor travel data can be identified, they can also be used for validation. The final outputs of this model would include estimates (trip tables) of visitor travel by mode.

## ■ 4.0 Long-Term Model Development

While the enhancements to the current model, presented in Section 3.0, are suggestions for implementation in the near term, it would be possible for TPB to, instead, put more time and resources toward moving directly to an activity-based model. The timeline for activity-based model development will depend on the TPB financial, staffing, and policy environment. At the minimum, an early step should be the development of a work program for movement to an activity-based model framework.

The rest of this section discusses implementation recommendations for the various components of an activity-based model, as well as recommendations concerning the model development process. Decisions regarding implementation should depend on planning analysis needs of the Washington D.C. area region and will also depend on resource constraints for model development and application.

## 4.1 Model Components

### Model Inputs

Most of the model inputs into an activity-based model are the same as, or similar to, those used for the four-step process. Therefore, TPB can use their existing zone structure, socioeconomic data, and highway and transit networks. The 4,000 zone system that TPB expects to have in the near term would be very appropriate for use within an activity-based model. Where possible, including highway and transit networks that vary by time would increase the model's sensitivity to time-of-day policy scenarios.

Activity-based models also require a regional household travel survey as input. TPB will easily be able to use their recently completed home interview survey for their activity-based model, since it includes detailed activity and travel information for each individual in selected households.

### Population Synthesizer

An activity-based modeling system should include a program to develop a synthetic population and the corresponding households for the entire modeled region. There are many existing population synthesizers. The population synthesizer used in the Atlanta Regional Council (ARC) model is available free of charge and can easily be adapted for use. Many programs, including the ARC program, use control totals for selected population categories based on U.S. Census PUMS data. Selected population categories may include: Income; Persons per Household; Workers per Household; Age of Head of Household; Nonworking Adults; Children; Dwelling Type; and Ethnicity.

TPB can choose to use all population categories or choose select categories. Income, persons per household, and workers per household were included in all reviewed urban models and, therefore, are suggested for selection at a minimum.

### Long-Term Choice Models

Activity-based models normally include long-term choice models. At a minimum, it is recommended that the TPB system include an automobile ownership model and regular usual workplace location model. Other optional long-term choice models, that have been included in the reviewed urban systems, include usual university location, usual school location, and work at home choice. Since the 2007/2008 household travel survey includes information on vehicle type and characteristics, including a vehicle type model may be a viable option.

### Daily Activity Pattern Models

The daily activity pattern modeling process is the area that varies the most among activity-based models examined. Therefore, there are a number of decisions that TPB needs to make regarding the daily activity pattern modeling process.

**Decision 1: Household Interactions –** The first decision that TPB should make is whether to include interactions among household members. While most models do include some household interactions, such as whether a vehicle is available or activity allocation, many models do not model intrahousehold partial and joint tours. The SFCTA, Sacramento, and Denver models, do not consider any partial or joint tours. The Columbus, Lake Tahoe, Atlanta, and MTC models do include some level of joint trip-making. Including household interactions increases the behavior realism of the modeling system. However, a modeling system with joint trip-making costs more money and takes more time to implement. Some modelers have noted that "the jury is still out" regarding whether the explicit inclusion of intrahousehold partial and joint tours produces enough additional accuracy to offset the cost of inclusion (Bradley et al., 2006).

The decision on whether to include household interactions or joint travel is heavily dependent on policy decisions being asked. If TPB is concerned with accurate analysis of HOV lanes, children's school travel, peak spreading, or work flexibility initiatives, then it is advised to model intrahousehold partial and joint tours.

**Decision 2: Sequence of Tour-Level Models –** Two previous tour-level model sequences have been implemented by the reviewed activity-based systems:

- **Sequence 1 –** In the Columbus, Lake Tahoe, Atlanta, and MTC models, the "mandatory" activities (work and school) are modeled first, including tour-level destination, mode, and time-of-day choice. Next, joint tours (among two or more household members) are modeled, followed by maintenance (e.g., shopping) and discretionary tours. Finally, the intermediate activities (stops) are modeled.
- **Sequence 2 –** For all other systems, all tour choices (destination, mode, and time-of-day) are modeled for each tour type (mandatory, joint, maintenance, discretionary) before modeling the next tour type. Notably, the tours of higher-priority types are scheduled, with the time periods used unavailable for subsequently modeled tours.

**Decision 3: Time-of-Day Choice Placement and Time Periods –** The tour-level time-of-day choice decision occurs in different places in the various models. For example, it occurs before destination and mode choice in the SFCTA models, between destination and mode choice in the Columbus, Sacramento, and Atlanta models, and after destination and mode choice in the New York and Denver models. There is no documented evidence to suggest that one particular placement of time-of-day choice is more beneficial than another. The decision may depend on the availability of the travel-time skims, which in turn is somewhat dependent on the decision of how many assignments to run, specifically whether demand will be aggregated into four or five time periods or be assigned at a more disaggregate level such as hourly demand. The more precision available from the skims, the more beneficial it is to place the time-of-day model before the mode choice model.

The SFCTA model uses five aggregate time periods for time-of-day choice; the more recent models use hour- or half-hour-long periods. TPB should consider using half-hour or hour-long periods, as shorter time periods allow for more options and flexibility when analyzing sensitivity to policy scenarios. However, retaining too many time periods may lead to an increase in run-times and data storage needs.

### *Trip Assignment*

To date, all of the modeling systems examined use traditional static equilibrium highway and transit assignment procedures that are the same as those used in conventional travel models. However, because each individual's activities and travel are simulated, activity-based modeling lends itself well to using a traffic microsimulation process. Including a traffic microsimulator within the system would cost more money and take more time to implement. Therefore, initially, TPB should consider using conventional methods, but create the modeling system in such a way that it can be paired with a traffic microsimulation system in the future.

## 4.2 Model Development Process

### *Phased versus Nonphased Approach*

TPB has the option to either develop the system all at once, or implement a phased approach. A phased approach would take longer and would cost more, but may be a good option if sufficient funding is only available over time or if short-term products help get political support. Otherwise, it is suggested that TPB not use a phased approach. There is no documentation on whether interim products are useful, and the additional cost and time of implementing a phased approach make it generally undesirable compared to developing the system all at once.

### *Consultant and Agency Involvement*

Consultants were used to develop and estimate models in almost all reviewed cases. The public agencies who eventually maintain the models always participate in data development and sometimes in model validation as well. The public agencies also can participate in model implication and estimation. It is recommended that the public agency be involved in the process as much as possible. Greater involvement, generally leads to a better understanding of the entire model over having the consultant do everything.

### *Time and Cost*

Implementing a nonphased approach will take from two to four years, depending on the modeling system complexity, agency involvement, and level of annual funding. A phased approach will take longer.

Consultant costs alone for model development and validation will be in the $750,000 to $1,250,000 range. Since TPB already has completed a household travel survey, there will be minimal data collection costs, except for obtaining additional observed data for validation purposes. In-house staff costs will depend on the level of agency involvement.

It is advised that TPB plan for implementation to take two to four years and cost $750,000 to $1,250,000 for consultant involvement. This would be in the range of $250,000 to

$450,000 per year not including in-house staff costs and data collection. This is above the current $150,000 per year in total costs that TPB currently has budgeted.

### Model Execution

There is generally no model execution time savings in switching from a trip-based model to an activity-based model. However, many activity-based models have achieved a one-day run time, using multiple processors. TPB can plan for about one day as a reasonable model run time, but should not expect run-time improvements over the four-step model.

Similar input data, such as travel-time skims are used as input into activity-based models as are used in trip-based models. If a standard trip assignment is used in conjunction with the activity-based modeling system, then similarly sized origin-destination pair trip matrices will be outputted as currently are outputted from the four-step model. This means that activity-based models do not eliminate the need for large matrices. Matrix size depends on the zone system. TPB should plan for approximately 7 to 10 GB of hard drive space for each model run.

Activity-based modeling systems produce different output based on different simulation runs, depending on the random number seeds that are used. Therefore, activity-based models have the ability to produce the most accurate set of outputs and eliminate simulation error, by running the system multiple times. However, regional-level statistics, such as VMT and VHT, do not vary much from run to run when using a standard trip assignment. Therefore, in practice the activity-based models will be run once with a fixed seed, which makes it easy to replicate results across platforms and users similar to the current four-step model.

TPB can either choose to run the models themselves, or have the models be run by outside agencies. Having a third party run the model generally costs more than running models in-house, but may be desirable under certain circumstances, such as staffing limitations. Since TPB currently runs their four-step model themselves, there is probably little reason to have a third party run their activity-based model.

## ■ 5.0 Next Steps

This memorandum reviewed potential options for updating and improving the TPB current four-step model and reviewed nine urban activity-based models currently in implementation or under development. The memorandum also presented options for near- and long-term model development enhancements.

Activity-based models are able to address the increasingly complex policy questions that are of concern for MPOs and state DOTs today that traditional four-step models cannot address. Therefore, while the enhancements to the current model are viable options for near-term implementation, it is advised that TPB put significant time and resources toward moving to an activity-based model.

In summary, the following are near-term next steps that TPB should consider for preparation toward implementing an activity-based model in the long term:

1. **Decide on Near-Term Enhancements to Four-Step Model –** It is advised that time and resources be invested toward developing an activity-based model, and, therefore, recommended (ideally) that further near-term enhancements to the four-step model not be undertaken beyond those already underway. However, if development of an activity-based model will not occur within the next few years, TPB should enhance their four-step model by updating every model component using the new 2008 household survey data, considering estimating destination and time-of-day choice models, and developing special generator models.

2. **Assess and Create Timeline and Budget for Moving Toward Activity-Based Model –** While TPB has a preliminary budget of $150,000 per year for activity-based model development, expansion of this funding should be explored to enable more rapid implementation of an activity-based model.

3. **Based on Timeline, Budget, and Policy Needs, Decide on Broad Model Components and Model Development Process –** TPB should decide on the broad model components outlined in Section 4.0, especially with regard to the level of intrahousehold interactions, time-of-day choice placement, and whether to implement a standard trip assignment or incorporate some form of disaggregate traffic assignment (e.g., dynamic traffic assignment or microsimulation).

4. **Focus on Updating Inputs to System (i.e., Network TOD, Validation Data) that can be Done In-House in the Near Term –** There are a number of in-house tasks TPB can undertake to prepare for the activity-based model development. Examples include creating network skims with greater temporal resolution and collecting detailed observed data that can be used for validation purposes.

## 6.0 References

Bradley, Mark and John Bowman. A Summary of Design Features of Activity-Based Microsimulation Models for U.S. MPOs. White Paper for the Conference on Innovations in Travel Demand Modeling, Austin, Texas, May 2006.

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TRB. 2007. Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction. National Research Council, Washington, D.C.

# Appendix A

*Comments on Mr. Allen Memorandum*

# Appendix A – Comments on Mr. Allen Memorandum

This Appendix presents review and comment on the tour-based modelling approach proposed by Mr. William G. Allen, Jr., P.E. outlined in a technical memorandum (Appendix B) to Mr. Ron Milone and Mr. Ron Kirby of MWCOG dated December 5, 2007. This review was performed at the specific request and direction of the National Capital Region Transportation Planning Board.

## ■ Memorandum Excerpts and CS Responses

Mr. Allen Memorandum:

*"Here are some of my thoughts on what is most commonly becoming referred to as tour-based modelling. This is the modelling of individual trips, rather than aggregate zone-zone travel. I worked on the NYMTC tour-based model and had a little exposure to the Columbus model."*

CS Response:

The definition in Mr. Allen's memorandum differs somewhat from what is used in current practice. Current practice tends to use the following definitions:

- Tour-based model – A model where the unit of travel is the tour, as opposed to the individual trip. A tour begins and ends at the home (or work), making one or more stops along the way. The trips that comprise the tour are modeled as related to one another, and both tour- and trip-level decisions such as destination, mode, and time of day are modeled.

- Activity-based model – A model where an individual is assumed to have demand for performing specific activities, rather than making trips. Since some activities are in different locations, travel is required and is modeled as a derived demand from the activity pattern. The activity pattern for each individual is converted to one or more tours. Therefore, all activity-based models are also tour based, but a tour-based model need not be activity based. The main difference, and main advantage of activity-based modelling, besides the realism of treating travel as a derived demand, is the disaggregate application to individuals, whose travel behavior can be summed to create aggregate results for any set of markets that can be defined by their characteristics.

Some aggregate tour-based models were developed in the 1990s (including the New Hampshire statewide model, which is still in use). However, since 2000, all tour-based models that have been developed in the U.S. are activity based. The NYMTC model is an activity-based model. There are four other operational activity-based models – for San Francisco County, Columbus, Sacramento, and Lake Tahoe – and several others currently under development.

Mr. Allen Memorandum:

*"I don't think most MPOs are quite ready yet to embrace this approach. The software is not yet mature and the approach is not yet standardized enough."*

CS Response:

The memorandum's statement that "the software is not yet mature" is true. Proprietary modelling software will not handle many components of tour- or activity-based models. However, experience from other areas means that the software is not really being developed completely from scratch, at least not by experienced activity-based model developers. The software to run the San Diego model, whose development is just getting started, is supposed to be open source.

It is true that the existing models do not use the same approach. However, there are many common elements to all modern models. At some point these common elements can begin to use a standardized approach and software.

It is too early to say whether large MPOs will embrace activity-based modelling. However, nearly all of the large MPOs in the U.S. are at least considering it.

Mr. Allen Memorandum:

*"As you probably know, the proponents of tour-based modelling cite several theoretical advantages, including:*

- *'true(r)' simulation of NHB tripmaking (i.e., trip chaining)*
- *better sensitivity to detailed HH and person characteristics (person age, inter-HH relationships)*
- *better modelling of the mode choice of tours (if you take transit to work, you almost certainly take transit home)*
- *more 'honest' simulation – calculations based on individual characteristics, not zonal averages"*

CS Response:

This list is accurate (although it applies to "activity-based models" by our definition, not aggregate tour-based models). There are other advantages, including the ability of activity-based models to aggregate results to the level needed. For example, for an environmental justice analysis, one could aggregate the model results for all members of a certain group (e.g., low income residents) to see the effects of a project or policy on that group, compared to others. Another is that, eventually, the individual activity pattern records will be able to be tied to a traffic microsimulation of individual vehicles.

The last bullet is probably the major advantage of activity-based models. One can simulate the characteristics of individuals in making travel choices rather than using aggregate or average values. For example, for a toll road analysis, one could simulate each individual's value of time, rather than assuming an average value. People who are more time sensitive would be more likely to use a toll facility while more "thrifty" people might opt for the free alternative. With aggregate models, all one can do is attempt to introduce market segmentation at a gross level.

Mr. Allen Memorandum:

*"One of the problems of tour-based modelling, in my opinion, is that modelers are trying to do too much with it. Some models try to estimate each person's activities throughout the entire day in terms of sequence and schedule (the whole idea of activity-based modelling makes me very nervous). This quickly starts to get very complicated – you are modelling things like: 'you can't use the car to go to work at 8:30 am because your wife used the car to go to work and she left at 8:00 am.' While it might indeed be more accurate to estimate that situation – it would certainly affect your choice of mode to work – I believe it stretches this approach beyond what is reasonable and beyond what the available data will support."*

CS Response:

It is important to recognize that not all activity-based models are this complex. Most existing and in-development activity-based models would not model the cited example. CS has advocated in many cases that the additional accuracy introduced by explicit modelling of all household interactions may not be worth the increased complexity and cost of model development and application (run time). In fact, many of the newer activity-based models (including Denver, Sacramento, and Seattle) have opted for this simpler approach.

Mr. Allen Memorandum:

*"Tour-based modelling allows you to model interactions and influences that you cannot do with an aggregate approach. However, one idea I have been kicking around is to simply convert an existing aggregate model into a very simple tour-based one, just as a 'proof-of-concept' exercise. I think it would actually be fairly simple to take any existing aggregate 4-step model and apply it in disaggregate fashion. The purists and academics would scoff that that would be a waste of time – you would not be taking full advantage of the features of tour-based models. True enough, but it would permit a direct comparison of the assignments, assignment accuracy, and sensitivity between the two approaches, and I don't believe anyone has done that yet. I believe it would tell you what you are giving up, or gaining, simply by changing the application process."*

CS Response:

CS has proposed this very idea to agencies who are looking for a phased approach to activity-based model development. CS believes this type of application could be a viable intermediate step before applying a full activity-based model, if the funds are not sufficient to develop an activity-based model all at once. However, as mentioned in the body of the task memorandum, CS advocates a non-phased approach to developing an activity-based model if there are sufficient available funds.

The disaggregate four-step model has not yet been done, as the memo notes. However, it is important to realize that such an approach is *not* tour based, as the interrelationships of trips and the tours that they form are not being modeled. It is still a four-step *trip-based* model, disaggregately applied. The disaggregate four-step model has the advantage that it greatly reduces aggregation error by simulating each household individually, incorporates accessibility into the trip generation step, and creates some components that could be adapted for the full activity-based model (mainly the trip-based models, the population synthesizer, and the process for creating trip tables from disaggregate trip records).

Mr. Allen Memorandum:

*"Supposedly, Citilabs is developing software specifically designed to develop and apply tour-based models. They announced an early beta version several years ago, but I don't think it has left the laboratory yet. You might want to contact them to see how far along it is and whether you could get a test copy yet."*

CS Response:

The idea that Citilabs is developing this software was presented by Mr. Mark Bradley at the 2005 Transportation Planning Applications Conference. CS has not heard anything about it since then.

Mr. Allen Memorandum:

*"The first step in any tour-based model is the population synthesizer… The resulting Household records each have the necessary attributes: number of persons by type, number of vehicles, income group, etc."*

CS Response:

Generally, Mr. Allen's description of a population synthesizer is accurate although it would be used only with a disaggregate model, what CS calls an activity-based model, not an aggregate tour-based model. However, "number of vehicles" has not yet been computed by any population synthesizer used in an activity-based model. Rather, a vehicle availability model, essentially the same type as is used in connection with some four-step models, is estimated and applied in a disaggregate manner, to individual households. This allows for the use of transportation system related variables (such as transit availability/accessibility) that might affect vehicle ownership.

Mr. Allen Memorandum:

*"(At this point, a digression. Some models use "tour" as the unit of travel, others use "journey." To the purist, a tour is a round trip that starts and ends at home, starts and ends at work, or starts and ends at school. A journey is part of a tour. So you make one work tour a day, but two work journeys. I'm not really sure how important this distinction is, or how consistent the usage of these terms is. The NYMTC model is based on journeys. In this memo, I will treat these terms as being interchangable, even though they aren't)."*

CS Response:

The NYMTC model is the only one that uses journeys. Every other model, including the aggregate tour-based models, uses the definition of tours beginning and ending at home (or work). The development of the NYMTC model began before any of the other activity-based models (although San Francisco was completed first), and I suspect that either the fact that it was being done for the first time or the complexity of modelling New York resulted in the simplification of using journeys instead of tours. There is no evidence that modelling journeys is better than modelling entire tours, and there are clear advantages to modelling the entire tour, since the return trip often affects decisions on the outbound leg.

Mr. Allen Memorandum:

*"One big change from 4-step models is that the travel purposes change. Work and School remain the same, but non-work trips are replaced by terms like Maintenance and Discretionary. Maintenance trips are those that you more or less have to make to sustain the household: grocery shopping, etc. Discretionary trips are those that are (sort of) optional, or at least have more flexibility in time and space: personal business, recreation, non-mandatory shopping, etc. The home-based vs. non-home-based distinction is no longer relevant."*

CS Response:

"Maintenance" and "Discretionary" are terms used by some models, but they are not industry standard. For example, the Denver model has the following tour purposes: work, school, shopping, escorting, social-recreational, and personal business.

Mr. Allen Memorandum:

*"The NYMTC model uses a logit model to estimate the probability of each person making each type of tour in a day. Ten different models are used, for each possible combination of person type and tour type. Each model has the same structure: a multinomial model of the probability of this person type making zero journeys, one journey, or two-or-more journeys (three-or-more for some purposes). These probabilities are based on the characteristics of the person and the HH, as you might expect."*

CS Response:

CS would characterize this approach as outdated. It is not used in the more modern activity-based models.

Mr. Allen Memorandum:

*"…the model makes one pass and allocates trips to attraction zones. It does not then check to see if those initially estimated attractions are approximately equal to the trip ends estimated by the attraction model – because there is no attraction model. The purists believe that if the attractions to a zone are underestimated by the logit process (i.e., below what a standard attraction model would have estimated), then that must mean that the zone suffers from low accessibility and therefore the attraction model must have been incorrect. I'm not sure I agree with this approach."*

CS Response:

It is true that neither tour-based nor activity-based models use trip attraction models. However, it is not necessary to have no attraction end constraints at all. They can be introduced, and they have been for some purposes. For example, the number of work activities in a zone should be related to the amount of employment in the zone. That being said, it does not make sense to ignore accessibility in determining the number of trips. If you improve highway access to a shopping mall, why shouldn't the number of trips increase? The best models consider attractions but do not constrain the trip ends in all cases. (This would be good practice for four-step models as well.)

Mr. Allen Memorandum:

*"I also have a problem with the assertion of some people that the sensitivity of travelers to, say, travel time is the same between the choice of destination and choice of mode."*

CS Response:

No tour- or activity-based model, that CS knows of, asserts that the sensitivity of travelers to travel time is the same between the choice of destination and choice of mode. The use of a logsum does not imply this at all, unless the logsum coefficient is 1.0 which is a value that CS would reject during model estimation.

Mr. Allen Memorandum:

*"My preference would be to use a very simple function of time or cost…."*

CS Response:

CS has, in fact, used simplified impedance functions in activity-based models. It is entirely consistent and practical.

Mr. Allen Memorandum:

*"This brings up the other major component of destination choice: the intermediate stop model. Many (all?) tour-based models incorporate some process to estimate, for each tour, the probability of making zero, one, or two (or 2+) stops on the journey between the two 'anchor' locations (an anchor is a major activity location, generally defined as Home, Work, or School). This process is conceptually simple, but computationally very complex, as you need to know the travel time and modal availability to all other intermediate candidate stop locations. It turns out that accurately modelling these intermediate stops is quite difficult, due to their almost random nature."*

CS Response:

Contrary to the memo statement, CS feels that modelling intermediate stop locations is not all that hard to do, and has been done in many models, including all of the U.S. activity-based models, the aggregate tour-based models that preceded them, and several models from outside the U.S.

Mr. Allen Memorandum:

*"I am not terribly familiar with tour-based TOD models, but I assume they attempt to estimate a start time for each tour, based on the characteristics of the person (and HH?), purpose, origin location, and congestion level. Some of the more intricate models also look at the travel time for each tour and the duration of each activity, trying to schedule each peron's movements throughout the day (e.g., you started a tour at 10:30 am, the first leg of which took 25 minutes and the duration of that activity took 1 hour, so you can't start the next leg until 11:55 am). That strikes me as carrying this process just a bit too far, although you certainly can't argue with the logic."*

CS Response:

Time-of-day models can indeed become too complex, and a simpler process may be more practical. Most of the existing models have simpler processes than the example shown above.

Mr. Allen Memorandum:

*"Tour-based models are considered most appropriate for 1/1 person-based travel. I have never heard of anyone using them for Commercial or Truck modelling."*

CS Response:

This is generally true, although Calgary, Canada has done some work on a tour-based truck model.

# Appendix B

*Mr. Allen Memorandum*

**William G. Allen, Jr., P.E.**

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**MEMORANDUM**

**To:** R. Milone, R. Kirby, MWCOG
**From:** B. Allen
**Date:** 5 Dec 2007
**Re:** Tour-Based Modelling

Here are some of my thoughts on what is most commonly becoming referred to as *tour-based modelling.* This is the modelling of individual trips, rather than aggregate zone-zone travel. I worked on the NYMTC tour-based model and had a little exposure to the Columbus model.

General
I don't think most MPOs are quite ready yet to embrace this approach. The software is not yet mature and the approach is not yet standardized enough. I just developed a new aggregate 4-step model for Baltimore last year, but I told them that their next major model update, in 5 years or so, would most likely use the tour-based approach. I suspect that most models developed after the 2010 Census will use that approach.

I used to be extremely skeptical that modelling individual trips would produce anything like the same results as an aggregate process. But after seeing the NYMTC results, I now believe that the aggregated results, i.e., the final trip table and assignments, will be comparable to that which you now achieve.

As you probably know, the proponents of tour-based modelling cite several theoretical advantages, including:

- "true(r)" simulation of NHB tripmaking (i.e., trip chaining)
- better sensitivity to detailed HH and person characteristics (person age, inter-HH relationships)
- better modelling of the mode choice of tours (if you take transit to work, you almost certainly take transit home)
- more "honest" simulation – calculations based on individual characteristics, not zonal averages

One of the problems of tour-based modelling, in my opinion, is that modellers are trying to do too much with it. Some models try to estimate each person's *activities* throughout the entire day in terms of sequence and schedule (the whole idea of *activity-based modelling* makes me very nervous). This quickly starts to get <u>very</u> complicated – you are modelling things like: "you can't use the car to go to work at 8:30 am because your wife used the car to go to work and she left at 8:00 am". While it might indeed be more accurate to estimate that situation – it would certainly affect your choice of mode to work – I believe it stretches this approach beyond what is reasonable and beyond what the available data will support.

Tour-based modelling allows you to model interactions and influences that you cannot do with an aggregate approach. However, one idea I have been kicking around is to simply convert an existing aggregate model into a very simple tour-based one, just as a "proof-of-concept" exercise. I think it would actually be fairly simple to take any existing aggregate 4-step model and apply it in disaggregate fashion. The purists and academics would scoff that that would be a waste of time – you would not be taking full advantage of the features of tour-based models. True enough, but it would permit a direct comparison of the assignments, assignment accuracy, and sensitivity between the two approaches, and I don't believe anyone has done that yet. I believe it would tell you what you are giving up, or gaining, simply by changing the application process.

Supposedly, Citilabs is developing software specifically designed to develop and apply tour-based models. They announced an early beta version several years ago, but I don't think it has left the laboratory yet. You might want to contact them to see how far along it is and whether you could get a test copy yet.

Computing
Gordon Schultz easily convinced me that at least in New York tour-based modelling was the only feasible way to apply that model, from a computing standpoint. That model has about 3,500 zones and a huge wealth of transit options. At one point, Gordon was talking about splitting each O/D pair into 64 possible submode/path combinations. The storage space for the skims and trip tables was going to be in the tens of gigabyte range and a huge proportion of the trip cells would be tiny, tiny fractions.

The NYMTC model includes about 8 million households, 19 million people, and 58 million trips. It soon became clear that estimating and storing 58 million trip records was far more efficient than dealing with dozens of 3,500 zone trip tables filled with zeroes and tiny fractions. 58 million 80-byte records is only 4.6 Gb!

I also developed a complete conventional 4-step aggregate model from the NYMTC survey data, for another project. Rutgers University is supposed to be hiring me shortly to help them do a direct comparison of that model with the NYMTC model. Should be interesting.

Another example: a few years ago I developed a new model for Charlotte. It has about 3,000 zones. I was storing the trip tables as ASCII files (don't ask – it's a long story), to the 6th decimal place. But I kept losing trips. I found out that I had to store the trips to the 12th decimal place in order to not lose *too many* trips. I think at the point where you have O/D cells with 0.000000000001 trips, that you are a serious candidate for tour-based models.

Population Synthesis
The first step in any tour-based model is the population synthesizer. It helps if you think of this as creating the Household and Person records from a standard home-interview survey, except that you have a 100% sample! The basic methodology is the same as you are using in your current households-by-size/income/autos model. For each TAZ,

you start with a base distribution of HHs and then use the marginal distributions to estimate the joint number of HHs by whatever dimensions you are using. As with several elements of tour-based models, Monte Carlo simulation is used to determine the characteristics of each HH and person.

The resulting Household records each have the necessary attributes: number of persons by type, number of vehicles, income group, etc. The Person records describe the type of each person in that HH. The NYMTC model uses a fairly simple categorization: Working Adult (over age 16), Non-Working Adult, and Child. Some of the newer models subdivide "Child" into Under 5 and Over 5. Other models have a separate category for 16-18 year olds. The idea is to separate children into those who don't go to school, those who go to school but can't drive, and those who go to school and can drive. For Adults, some models have subcategories by gender and for Workers, some models distinguish between full-time and part-time workers.

All of the information needed for population synthesis is available from Census Public Use Microdata Sample (PUMS) data. I don't know if there yet exists one, standard methodology for doing that synthesis. I'm also not sure if the 2010 Census will include PUMS; I sure hope so.

For forecasting, you still have to estimate future statistics on income, vehicle ownership, labor force participation, and age. Those are used to synthesize the future year population.

Most tour-based models still maintain and use a TAZ structure. The population synthesizer uses whatever data you have at the TAZ level and attaches the TAZ number to each HH in that TAZ.

Tour Frequency

The next step is the tour-based analog of trip generation: tour frequency.

(At this point, a digression. Some models use "tour" as the unit of travel, others use "journey". To the purist, a *tour* is a round trip that starts and ends at home, starts and ends at work, or starts and ends at school. A *journey* is part of a tour. So you make one work tour a day, but two work journeys. I'm not really sure how important this distinction is, or how consistent the usage of these terms is. The NYMTC model is based on journeys. In this memo, I will treat these terms as being interchangable, even though they aren't.)

One big change from 4-step models is that the travel purposes change. Work and School remain the same, but non-work trips are replaced by terms like Maintenance and Discretionary. *Maintenance* trips are those that you more or less have to make to sustain the household: grocery shopping, etc. *Discretionary* trips are those that are (sort of) optional, or at least have more flexibility in time and space: personal business, recreation, non-mandatory shopping, etc. The home-based vs. non-home-based distinction is no longer relevant.

The NYMTC model uses a logit model to estimate the probability of each person making each type of tour in a day. Ten different models are used, for each possible combination of person type and tour type. Each model has the same structure: a multinomial model of the probability of this person type making zero journeys, one journey, or two-or-more journeys (three-or-more for some purposes). These probabilities are based on the characteristics of the person and the HH, as you might expect.

But what is most interesting and relevant is that the probabilities are *also* based on:

- the characteristics of other persons in the HH
- other trips already made by this person

For example, the probability of a Non-Working Adult making a Work journey is sensitive to whether or not there are any Children in the HH. The probability of a Worker making a Maintenance journey is sensitive to whether that Worker was previously estimated to make a Work journey. The trip purposes are assigned a priority – School, University, Work, Maintenance, then Discretionary and the models are applied in that order. So by the time you apply the model of "Maintenance Journeys by Workers", you already know whether or not you've estimated that that Worker went to work that day. These interactions turn out to be statistically significant and logically relevant to travel by individuals. Their explanatory power goes a long way towards explaining the attractiveness of tour-based modelling.

Mode/Destination Choice

All tour-based models (I believe) use a logit model to allocate trips to attraction zones. Some combine the destination and mode choice into one model, to reflect that these choices are somewhat conditioned on each other. Most of these models are singly-constrained, not doubly-constrained as in a standard gravity model application. That is, the model makes one pass and allocates trips to attraction zones. It does not then check to see if those initially estimated attractions are approximately equal to the trip ends estimated by the attraction model – because there is no attraction model. The purists believe that if the attractions to a zone are underestimated by the logit process (i.e., below what a standard attraction model would have estimated), then that must mean that the zone suffers from low accessibility and therefore the attraction model must have been incorrect. I'm not sure I agree with this approach. Although most attraction models certainly have their failings, I'm not sure I'm ready to throw them away. However, trying to incorporate an attraction end constraint poses some processing difficulties of its own (I'm still working on that).

I also have a problem with the assertion of some people that the sensitivity of travellers to, say, travel time is the same between the choice of destination and choice of mode. This is the premise that got Messrs. Bruggeman and Schultz into trouble with the infamous *composite impedance* function. You may remember that this was tried in the original Dulles Corridor Rail model, was later found to be quite problematic, and was replaced by *composite time.* Part of the problem in the original composite impedance calculation was that the coefficients on time, cost, etc. were the mode choice coefficients. This was touted as a way to "connect" the destination choice to the mode choice, but it didn't work out.

My preference would be to use a very simple function of time or cost (I'm not sure you need both) and transit availability in the destination choice function. Then leave mode choice as is. In fact, most mode choice models already use the logit function, so they typically don't change much between an aggregate 4-step model and a disaggregate tour-based model. The biggest difference is in application – for a person who stops on the way to work, you look first at the transit service to the final destination (work) zone, then at the transit service between home and the intermediate stop zone.

This brings up the other major component of destination choice: the intermediate stop model. Many (all?) tour-based models incorporate some process to estimate, for each tour, the probability of making zero, one, or two (or 2+) stops on the journey between the two "anchor" locations (an *anchor* is a major activity location, generally defined as Home, Work, or School). This process is conceptually simple, but computationally very complex, as you need to know the travel time and modal availability to all other intermediate candidate stop locations. It turns out that accurately modelling these intermediate stops is quite difficult, due to their almost random nature.

## Time of Day

Almost all current aggregate 4-step time of day models are crude and simple factor-based approaches that are fundamentally flawed and don't account for things like the rolling peak or differences in traffic congestion. This is an area where tour-based models have the potential to make major improvements. But if you're not careful, you can get a little crazy.

I am not terribly familiar with tour-based TOD models, but I assume they attempt to estimate a start time for each tour, based on the characteristics of the person (and HH?), purpose, origin location, and congestion level. Some of the more intricate models also look at the travel time for each tour and the duration of each activity, trying to schedule each peron's movements throughout the day (e.g., you started a tour at 10:30 am, the first leg of which took 25 minutes and the duration of that activity took 1 hour, so you can't start the next leg until 11:55 am). That strikes me as carrying this process just a bit too far, although you certainly can't argue with the logic.

## Commercial Trips

Tour-based models are considered most appropriate for I/I person-based travel. I have never heard of anyone using them for Commercial or Truck modelling. The NYMTC Commercial and Truck models use the conventional 4-step aggregate approach. However, I have been working on converting your new Commercial trip model into a disaggregate trip-based approach. I am doing this for several reasons: 1) to see if I could actually do it, 2) to test the concept, 3) to see how the link volumes would differ from the aggregate approach, 4) to see how it affects file size and running time. This work is still in progress. I am having some difficulties with the attraction constraint process (see above). I am hoping to finish it soon, after which I'll show you what I've done.

I hope this has been helpful. I would be glad to discuss any of these items with you, at your convenience.

# Framework for Before-and-After Study of HOV Network Effects Due to New HOT Lanes

task

**memorandum**

*prepared for*

**National Capital Region Transportation Planning Board**

*prepared by*

**Cambridge Systematics, Inc.**

*November 20, 2009*

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# Framework for Before-and-After Study of HOV Network Effects Due to New HOT Lanes

## 1.0 Introduction

The next several years offer a unique opportunity to observe changes in traveler behavior in response to the gradual introduction of a more expansive high-occupancy vehicle (HOV) network as the planned high-occupancy toll (HOT) lane projects are completed in sequence in Northern Virginia. This memorandum details a proposed framework to study the HOV network effects to result from the completion of these projects, with a special focus on before-and-after studies. The proposed framework is flexible, offering recommendations appropriate for varying expenditure levels.

## 2.0 Review of Practice

Given the focus on the development of a plan to evaluate the HOV network effects of HOT lanes before and after implementation, Cambridge Systematics turned to existing before-and-after studies for guidance. The following studies and reports were identified as being potentially useful in guiding a framework for the HOT network evaluation effort:

- Twin Cities Freeway Ramp Metering Evaluation;
- Minnesota DOT HOV Evaluation Study;
- Minnesota DOT I-394 HOT Evaluation Study;
- Portland ITS Integration Evaluation;
- NCHRP Synthesis 364: Estimating Toll Road Demand and Revenue; and
- NCHRP Synthesis 377: Compilation of Public Opinion Data on Tolls and Road Pricing.

The key points of each study and report are outlined in the subsections that follow.

### Twin Cities Freeway Ramp Metering Evaluation

For the Minnesota Department of Transportation (DOT), Cambridge Systematics led a team of consultants that conducted an intensive real-time evaluation of the impacts of temporarily shutting down the region's system of 430 ramp meters. This study, performed in response to a legislative mandate, required an intensive effort to develop and obtain approval for an evaluation plan within one month; collecting six weeks of before-and-after field data within a narrow time window; and analyzing and preparing the findings quickly. The evaluation included an analysis of the changes in traffic operations, safety, consumer response, and benefit/cost; a massive data collection effort on four interstate highway corridors and adjacent arterials in the region; and the completion of two waves of 750 telephone surveys and focus groups. The findings of the study document changes in actual traffic operations in the region as a result of the ramp meter shutdown, as well as changes in public attitudes toward ramp meters on a corridor-specific and regionwide basis.

Removing the metering system entirely led to systemwide degradation:

- A 9 percent reduction in freeway volume.
- A 22 percent increase in freeway travel times.
- A 7 percent reduction in freeway speeds, which contributed to the negative effect on freeway travel times. The reliability of freeway travel time was found to decline by 91 percent without ramp meters.
- A 26 percent increase in crashes, which was averaged for seasonal variations.

Cambridge Systematics worked with Minnesota DOT on a series of recommendations to improve the ramp metering system and impose less of a burden on drivers entering the freeway system while maintaining the benefits of the meters.

## Minnesota DOT HOV Evaluation Study

For the Minnesota DOT, Cambridge Systematics conducted a legislatively mandated evaluation of the opening of HOV lanes on Interstates 394 and 35W to mixed-flow traffic. As the study was nonintrusive, modeling and market research was used to estimate impacts on traffic flow and congestion, transit and HOV use, and safety. The evaluation included: the development of evaluation plans; secondary research; market research; data collection; modeling; a benefit/cost analysis using the Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS); and a white paper discussion on the use of HOT lanes as a compromise to opening the HOV lanes to all traffic.

Several aspects of this study have relevance to a framework for before-and-after study of HOV network effects due to new HOT lanes in the Washington, D.C., area, including:

- Usage of a regional model in the toolbox for interpretation of results;
- Usage of market research techniques to understand traveler attitudes and preferences;
- Usage of field data on characteristics of current travel (e.g., actual vehicle and person throughput for both the general-purpose and HOV lanes at various screenlines, HOV violation rates, transit ridership); and
- Usage of IDAS sketch-planning analysis tool to help quantify benefits and costs of the changes explored.

## Minnesota DOT I-394 HOT Evaluation Study

Recognizing the use of the I-394 MnPASS deployment as a test bed for evaluating the viability of the HOT lane concept and the broad interest in the application, Minnesota DOT implemented a comprehensive evaluation effort to assess the system with distinct evaluation teams covering a public attitudes evaluation and a technical evaluation.

The technical evaluation effort (led by Cambridge Systematics) focused on identifying and quantifying the system impacts of the deployment on travel time, speed, safety, throughput, and environmental factors. The evaluation also assessed enforcement issues and the reliability of the HOT lane operational components. Stakeholder input was gathered to identify the evaluation goals and objectives. A detailed evaluation plan was developed to identify specific performance measures that support the goals and objectives and identify data collection and analysis plans to assess the HOT lane impacts on the selected performance measures. System data collected before and after the implementation were compared to provide the basis for the impact analysis.

The technical evaluation of the I-394 MnPASS deployment included the identification of multiple evaluation objectives to be assessed in the course of the evaluation. While some of these issues required the simple documentation of issues, others identified objective specified hypotheses to be tested during the course of the evaluation. The evaluation hypotheses were important in specifying the data that needed to be collected and the analyses that needed to be performed.

Given the dynamic nature of the traffic conditions on I-394, observed traffic patterns in the before-and-after periods were not anticipated to be identical even in the absence of the MnPASS deployment. Therefore, the evaluation approach specifically was designed to anticipate and control for these influencing factors, to the degree possible, in order to isolate the change in conditions directly resulting from the MnPASS strategy.

In order to isolate the impact of the MnPASS deployment, the evaluation approach was designed to analyze data collected over broad time periods both before and after the implementation to provide a wide sampling of travel conditions under a variety of influencing factors. This provided the opportunity to group and compare conditions on similar travel days both before and after the implementation, and minimizes the erroneous identification of MnPASS impacts based on averages from a limited sampling on diverse travel days. This also provided the opportunity to assess how the impacts of the MnPASS system varied based on different conditions (e.g., good weather days versus bad weather days, Tuesdays versus Fridays, etc.) in order to provide Minnesota DOT with feedback on when and under which conditions the system is more or less effective.

To accomplish this, the evaluation approach was designed to make maximum use of automated data sources, such as data from the Regional Transportation Management Center detectors. The use of these automated archived data sources also provided the opportunity to obtain historical data that, in many cases, was further used to understand and control for cyclical variations and trends. Field-collected data were used to supplement the automated data by collecting particular parameters that were unavailable through automated sources (e.g., vehicle occupancies), and were used to provide validation data for the automated sources. The reliance on these automated data sources allowed for a broader set of evaluation objectives and provided the opportunity analyze the variability of impacts occurring over a longer time period and for a greater variety of days. This also increased the opportunity for Minnesota DOT and other researchers to recreate the evaluation framework for future monitoring and evaluation efforts.

To further help control for regional changes in travel patterns, the evaluation compiled and analyzed both before-and-after data from a similar HOV lane section of the I-35W corridor to provide control data. Any changes observed on the I-35W HOV section between the before and after periods were used to represent and control for regional changes to travel patterns when analyzing the I-394 data.

The Minnesota DOT I-394 HOT Evaluation Study offers a number of lessons useful in informing the framework for evaluation of the travel changes in the Washington, D.C. area due to the expanded HOV network, including the importance of identifying evaluation hypotheses to inform the data collection, the usage of automated data collection to provide a depth of longitudinal data, and the use of a control corridor to help address external changes in regional travel patterns.

## Portland ITS Integration Evaluation

For the Federal Highway Administration (FHWA), Cambridge Systematics, as part of a team, evaluated the impacts and lessons learned from an integrated ITS deployment in the Portland, Oregon metropolitan area. The project integrated transit management, arterial management, and traveler information components to operate as a coordinated system. Cambridge Systematics focused on mobility impacts and institutional issues stemming from the deployment. Like with the Minnesota DOT HOT Evaluation Project, evaluation goals were expressed in terms of hypotheses which allowed the identification of appropriate measures of effectiveness and the data needed (and methods of collection) to support their testing. This project also used several transit-based data collection techniques that could be useful in a Washington, D.C. area evaluation, including speed tracking of buses.

## NCHRP Synthesis 364 – Estimating Toll Road Demand and Revenue

This Synthesis report focuses on existing modeling practice for estimating toll road demand and revenue. While the vast majority of cases used a four-step model, there was little consensus on the state of the practice of toll modeling, particularly with respect to the time period estimated (peak hour, peak period, or daily) and the treatment of pricing within the model. An analysis of the forecasts themselves indicates that the state of the practice is not delivering acceptable forecasts. Only 5 of 26 examined cases reasonably could be considered within 10 percent of their opening day and five-year forecasts (with an additional toll road in Georgia that consistently outperformed its revenue forecasts). There was not sufficient information in the synthesis report to indicate the nature of the forecasts, whether the acceptable forecasts used before-and-after studies, for example, or whether the acceptable forecasts were modeled using the regional model or were stand-alone forecasting exercises.

### NCHRP Synthesis 377 – Compilation of Public Opinion Data on Tolls and Road Pricing

This Synthesis presents a survey of public attitudes towards tolls, not a synthesis of existing practice or of forecasting tools. The concept of HOT lanes generally was supported by the public, overwhelmingly so in Southern California. One outlier was the Puget Sound region where the public strongly disliked the concept of HOT lanes. However, the public clearly rejected variable tolling or other congestion-related pricing that attempted to shift demand. The findings reported in the synthesis report could be used to inform surveys (either revealed- or stated-preference surveys) collected as part of the evaluation effort. It does suggest that public acceptance of variable toll pricing can be a factor in implementation, if that is one of the features of the proposed HOT lane scheme. Should public opinion be an aspect of the desired evaluation of the expanded regional HOV opportunities created by the new HOT lanes, this report could provide some useful examples.

## ■ 3.0 Foundations for an Evaluation Study

### Define the Study Corridors

The first step in developing an evaluation plan would be to examine the locations of the proposed HOT lanes and determine how many study corridors should be established. The proposed HOT lane conversion and expansion on I-95/I-395 could be treated as one, two, or more study corridors depending on which dividing line(s) are chosen. The proposed HOT lanes along the Capital Beltway (I-495) will be built in Virginia from Springfield to the Dulles Toll Road. This should be treated as a single circumferential corridor (with potentially different segments of interest).

It will be particularly important that the relevant HOV lanes are adequately represented as part of the evaluation, both in terms of data gathering to measure impacts and ensuring that the regional model can capture any proposed modifications to the HOV lanes. I-395 currently has a two-lane reversible HOV 3+ facility. I-66 is a restricted facility with two lanes each way inside the Beltway from I-495 into D.C. It operates as HOV 2+ inbound in the morning and outbound in the evening, while the opposite direction is without restriction during each time period. Outside the beltway, the inbound left lane of I-66 is designated HOV 2+ during the morning and the outbound left lane is designated HOV 2+ during the evening. I-495 currently has no HOV lanes, though the following roads that connect with I-495 do have HOV facilities: I-270, U.S. 50 in Maryland, and the Dulles Toll Road. A control corridor (or corridors) should be selected to help account for regional changes during the evaluation period.

### Determine the Markets of Interest

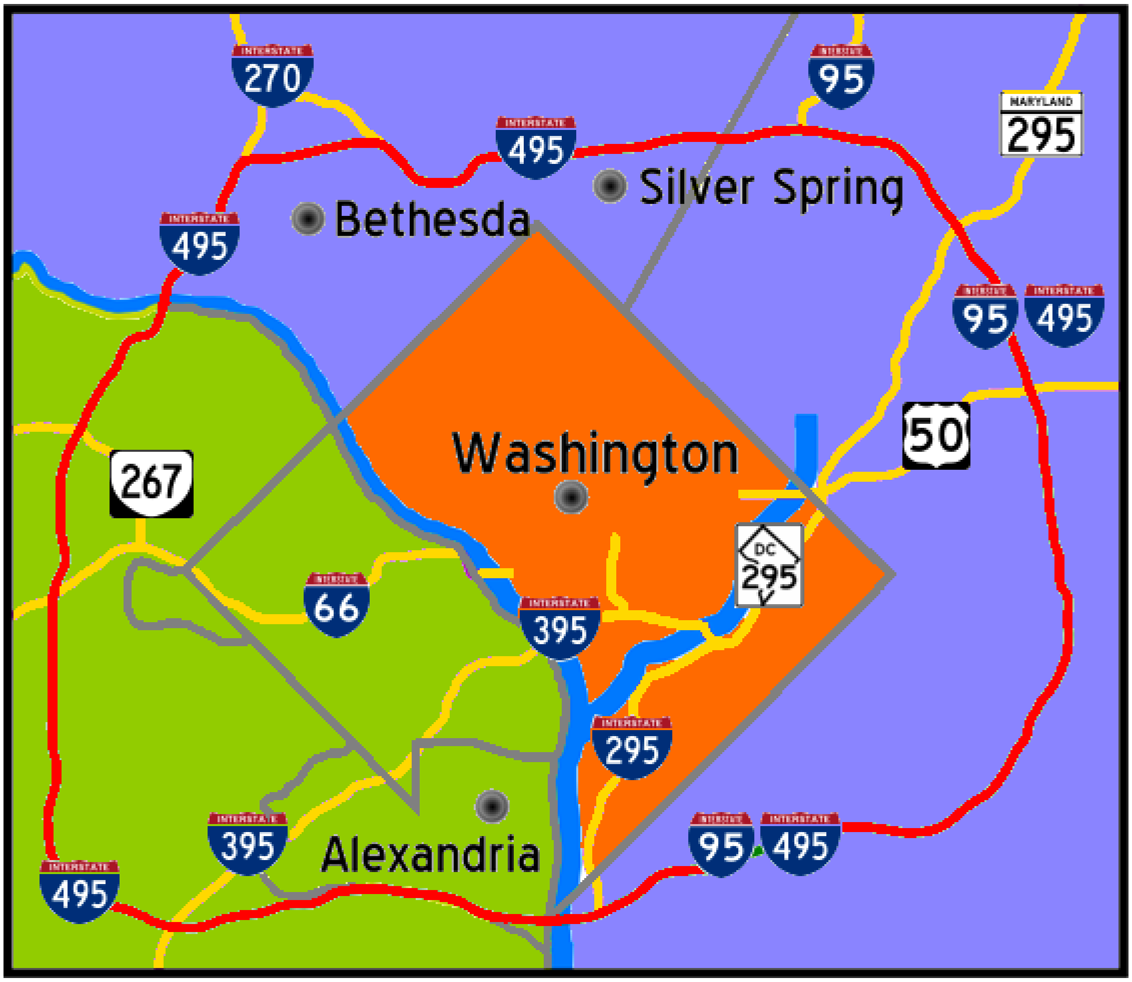
For each study corridor, patterns of use would need to be established both before and after. The regional model could be used for this purpose. In particular, select link analyses could be used to determine the travel markets represented by users of the facilities (e.g., are the traffic movements predominantly suburb to D.C., or suburb to suburb). This could be performed at key locations.

Commercial vehicle surveys could be undertaken to help derive estimates of commercial traffic on these facilities should it be an interest area. While heavy trucks typically are prohibited from using HOV/HOT lanes, the prohibition is uncertain for smaller trucks and delivery vans. In either case, the impact of HOT lanes on commercial traffic (through the removal traffic on the regular lanes) needs to be carefully considered.

## Identify Competing Facilities and Services

Determination of travel markets served by corridors under study (as described in the preceding section) can assist in the identification of potential competing facilities and services which might also need to be monitored to support before-and-after study. Figure 1 highlights key highway facilities serving the D.C. region core.

**Figure 1. Major Highway Facilities in Metropolitan Washington**



Potentially, monitoring of I-66, I-295, U.S. 50 in Maryland, and other radial routes could be useful to performing an evaluation. When looking at other facilities, it would be best to collect the same data in the same manner as on the changed facilities to best enable analysis and meaningfulness of comparisons. For I-395 in particular, the Blue Line of the Metro (particularly as the Franconia-Springfield and Van Dorn Street stations each have large park-and-ride facilities) and the Fredericksburg Line on VRE may serve similar travel markets and also warrant monitoring of changes. In turn, this will require careful consideration on how to measure transit riders consistently with the I-395 users. It also may lead to considering broadening any stated-preference surveys performed to include transit riders in the corridor and not to restrict the research to automobile commuters.

## ■ 4.0 Experimental Design and Data Collection

### Develop Hypotheses

While data availability is a key consideration for the evaluation framework, it is perhaps more important to consider the questions that the evaluation is designed to address. A number of potential hypotheses are suggested:

H0a: *Introduction of HOT to existing HOV 3 facility does not adversely effect HOV volume.*

I-395 will be widened in conjunction with introducing the tolls which will somewhat confound isolating the effects, but this hypothesis will yet be important to test as it has implications both in the region and nationally.

H0b: *Introduction of HOT to the circumferential facility will increase HOV volumes.*

Currently, I-495 has no HOV priority treatments (i.e., there are only general purpose lanes on the Beltway today). The introduction of the HOT facility will greatly expand the network of available carpool lanes and open up new carpool travel markets. It is important to understand if doing so increases the usage of HOV and in what markets.

H0c: *Change from HOV 2 to HOV 3 decreases volume.*

Should HOV lane occupancy restrictions be adjusted so that three people traveling together (HOV 3) are required to use the existing HOV 2+ lanes, this should decrease carpool volumes on the HOV lanes.

H0d: *As congestion on parallel facilities increases, HOT use increases.*

The expectation is that HOT use will increase as congestion degrades the general purpose lanes on parallel facilities. Perhaps the most significant difficulty with capturing HOT use in a regional model (as opposed to real world conditions) is that classes used in assignment typically do not contain information on income (personal or household) that would affect willingness-to-pay the HOT charges.

H0e: *As congestion increases, demand shifts to peak shoulders.*

To avoid congestion and, to some extent, paying higher HOT charges, travelers that want to use I-395 or I-495 will shift away from the peak hour into the shoulders of the peak. It is unclear whether the HOT option will reduce congestion in general purpose lanes to eliminate peak spreading, or if it will continue regardless of their implementation. Peak spreading could occur on the general purpose lanes as well as the HOT lanes (i.e., higher tolls will be charged during peak periods).

H0d: *If generalized cost increases, transit mode share will increase.*

While the Metro Blue Line and VRE commuter rail lines are imperfect competitors with I-395, some non-negligible portion of drivers could make a switch, although it is unclear (at the outset of the evaluation) what the price in terms of delay on congested roads or alternatively the HOT charge would lead to in terms of mode shift. (The DRPT I-95/I-395 Transit/TDM Study anticipated that most toll users would be drawn from current single occupant commuters, based in part on a stated preference experiment). Since this competition is only relevant for I-395 users who have destinations in Alexandria or the District, it suggests that segmenting the population by destination might be an important step in the evaluation.

H0e: *If generalized cost increases, long-term destinations, particularly workplace, will shift away from the District.*

As transportation costs increase, it is expected that people will shift their home or workplace location to lower their transportation costs. This suggests that in any revealed-preference survey, questions regarding long-term destination choice should be incorporated if possible.

For each hypothesis, the study team will want to take measurements "before" the introduction of new facilities, as well as repeating the measurements "after" the facility is introduced – preferably under steady state conditions. The hypotheses will determine what kinds of information need to be gathered, which, in turn, will inform the study design, particularly if unusual data is required (e.g., attitudes regarding long-term workplace location and relocation).

The other reason to work backwards from a series of hypothesis is to undertake a review of the regional model early in the project to determine which if any of the hypotheses can be tested in the regional model and those which can be tested but only after modifications to the regional model. Some hypotheses might not fit well within the context of the regional model because the dimensions do not fit or it relies on data that is simply not available. The study team also would want to evaluate regional model sensitivities, particularly the treatment of cost terms. While the evaluation study will primarily be used to evaluate the performance of a major implementation of HOT lanes in a major metropolitan region, it also will be important to note whether regional models have to be updated to accurately forecast HOT usage.

## Gather Performance Data

Accepting the strawman set of hypotheses presented above and considering the data, therefore, necessary to support their testing, the following performance data would be collected:

- Travel times in corridor, as well as for competing routes:
  - Both from region model and from speed runs (if these exist); and
  - Times for general purpose lanes and HOV lanes (where these already exist).
- Average point-to-point travel times for key roadway segments.
- Estimates of reliability by measuring deviation from the average values.
- Ideally, these travel times would be derived for morning peak, midday, and evening peak time periods.
- Repeat the same measures using estimates of throughput – most likely traffic counts and modeled auto volumes on these segments.
- The study team must do a careful inventory to determine if the counts or indeed the modeled volumes can be provided at a disaggregate level, either peak hour or peak period. Have classification counts (allowing us to distinguish trucks from cars) be carried out at any locations of interest.
- The cooperation of relevant transit agencies would be helpful to arrange for data collection of boardings and alightings in the corridor(s) of interest. Potentially an on-board survey could be arranged before and after the introduction of HOT lanes on each facility. Automated transit data collection opportunities could also be explored (e.g., vehicle speed, boardings only).

Additional effort must be taken to collect data during the spectrum of time periods, including the peak hours, the peak-hour shoulders, and off-peak periods. The assumption is that, at a minimum, peak and off-peak data must be collected. Experience in past evaluations suggest that establishing and using a core database of information from continuous automated data collection sources can be very helpful.

## Gather User Data

The best method to understand existing users of the I-395 and I-495 corridors is to conduct a survey of drivers, potentially using license plate matching technology to identify vehicles on these facilities. The number of locations to collect license plates could be based on the number of subsections established in the first stage of the research.

Any survey must be designed to track current usage of the facilities (route choice is often omitted from conventional travel diaries, though is taken into consideration when license plate matching is done). If the survey is a stated-preference design, then willingness to pay must be considered. Ideally, the study team would follow-up with the same users after each HOT facility had been opened. This may be achieved by asking survey users (selected on the basis of their current use of the facility) if they are willing to be contacted again.

In addition, the study team could investigate whether a preexisting market research panel based on Metropolitan Washington residents would identify enough commuters that actually use the facilities and/or live and work in the corridors. The panel approach may lead to lower bias on questions regarding future HOT usage (the after case). It also would theoretically allow transit riders in the corridor to ask if they would switch back to driving in the HOT lanes or the general purpose lanes if they improved sufficiently. One advantage of panel studies is that panel members already would be accustomed to being contacted for follow-up surveys.

## ■ 5.0 Evaluation

After the before-and-after data has been gathered, the study team can examine if the profile of measures above changes in terms of response to congestion and/or pricing, providing statistical indices for before-and-after comparisons. In cases where the data will directly support or disprove a hypothesis, this clearly can be indicated with a separate table of results. Based on the findings, the study team could summarize many aspects of the HOT implementation in Metropolitan Washington for consideration in future local expansions, as well as to offer lessons learned for other regions, including addressing questions such as:

- What is the usage on the new HOT lanes, with particular attention to the SOV/HOV split; how were project revenues impacted?
- What are the impacts on the regular lanes, as well as on competing facilities?
- How might usage of the HOT lane change based on different HOT charges? Will peak spreading continue on facilities where HOT lanes have been added, and what are the broader implications of this finding?
- Will HOT lanes positively or negatively impact the regional transit systems?

The final result from evaluation studies of this nature usually is one or more white papers on HOT implementation where the study team draws on findings and indicates the transferability to other regions.

## ■ 6.0 Next Steps/Recommendations

The next step in building an evaluation framework would be to begin the process of identifying a set of evaluation goals, and within each evaluation goal, a set of hypotheses to be tested. Measures of effectiveness required to test for the hypotheses then could be identified leading to a list of data elements required for the evaluation. A high priority should be placed on identifying data elements requiring advanced automated data collection capabilities to allow any regional limitations in this area to be addressed sooner rather than later. Data collection then should proceed across the required dimensions to permit the evaluation of the hypotheses at the midpoint and conclusion of the HOT network expansion.

# Improving the Model's Sensitivity to Land Use Policies and Nonmotorized Travel

task

**memorandum**

*prepared for*

**National Capital Region Transportation Planning Board**

*prepared by*

**Cambridge Systematics, Inc.**

*with*
Vision Engineering and Planning, LLC

*November 20, 2009*

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# Improving the Model's Sensitivity to Land Use Policies and Nonmotorized Travel

## ■ 1.0 Introduction

One of the stated planning objectives of the Transportation Planning Board (TPB) is to seek improved coordination between land use and transportation planning. Several actions have recently been taken to further this objective, including:

- Identification of 58 Regional Activity Centers and Clusters (RACC) along major transportation facilities where focused development exists or is planned – the RACCs contain more than 70 percent of the region's current and future employment, and more than 40 percent of the region's current and projected households;

- Completion of a household travel survey which was specially formulated to include adequate representation of travel behavior associated with the RACCs;

- Development of a new traffic analysis zone (TAZ) system to permit the study of observed travel behavior at a finer scale; and

- Conflation of the regional highway network to the NAVTEQ street centerline map to improve its accuracy and allow for enhanced coding detail.

The opportunity now exists, as TPB moves into the development of Version 2.3 of the regional model, to tap the new data sources and shape the functionality of the tool to improve the regional model's sensitivity to land use and transportation policy in a practical way.

This memorandum was developed to provide thoughts on how best to improve the regional model's sensitivity to land use and transportation in a practical way. Section 2.0 presents background review of recent modeling practices in other Metropolitan Planning Organizations (MPOs). Sections 3.0 and 4.0 discuss short- and long-term approaches, respectively, to model enhancement for TPB. In addition, Appendix A was prepared to provide an overview of directions in land use modeling and Appendix B lists references.

## ■ 2.0 Background Review

This section discusses the subject of model sensitivity to land use policies and nonmotorized travel generally. All travel demand models require land use inputs. However, the level of detail and number of attributes through which the location, intensity, and type of future households and employment are represented vary widely.

## 2.1 Including Consideration of Land Use Policies

Transportation Research Board (TRB) Special Report 288: Metropolitan Travel Forecasting – Current Practice and Future Direction (2007) found that it was common practice to require forecasts of population, households, and employment as input to the travel forecasting process. Although only about half of all MPOs surveyed also forecast one or more of household size, automobile ownership, or income; among large MPOs the proportion doing so is undoubtedly large. Approximately 15 percent of all MPOs use a housing type variable in their trip generation formulations.

A wide variety of land use policies could potentially be desirable to test in terms of impacts on transportation behavior. However, since not all underlying traveler response factors can be isolated and because there is a two-way relationship between transportation and land use, it should be expected that there will be uncertainty in forecasts related to this issue and that not all aspects of different land use policies can be explored within the regional model. That is, it should be expected there will be some policy differences that the regional model will be sensitive to and some that it will not be. However, it is reasonable to expect that the travel behavior impacts of concentrated growth patterns versus non-concentrated growth patterns should be discernable from regional travel model forecasts. Additionally, the impact of transit-oriented development on transit demand should be discernable. Differences due to specific urban design attributes may be less reasonable to expect the regional model to be sensitive to.

Neighborhood land use density variables and accessibility variables have been shown to improve the performance of trip-based travel demand models (Purvis, 1998) and can serve to capture the influence of concentrated growth and transit-oriented development policies, especially when combined with the use of a finer-level TAZ system and detailed transportation network and land use coding. These measures can feed into many places in travel demand forecasting process, including: household characteristics models (e.g., automobile ownership forecasting); trip generation models; trip distribution models; and mode choice models.

Density and accessibility are attractive variables to use in modeling because both are objective measures that, depending on their formulation, do not necessarily require additional data to be assembled for calculation. Density represents the intensity of land use activities, usually measured as the ratio of some unit of activity (residential and/or employment) over some unit of land area. Density, as it implies various neighborhood characteristics such as transit level of service, pedestrian friendliness, land use mixing, etc., is strongly correlated with travel behavior, including auto ownership, trip generation, and mode choice.

A variety of density measures are potentially available for modeling purposes, depending on the underlying data availability. The following are a number of different density measurements:

- **Net Density –** The ratio of activity measure to the land area devoted specifically for that activity (e.g., total households/residential acres, or total employment/ commercial, and industrial acres).
- **Gross Density –** The ratio of activity measure to the total land area (e.g., total households/total acres, or total population/total acres).
- **Composite Density –** Looking at population and employment activities together (e.g., total population and employment/total acres, or the ratio of households to total employment).

As density measurements are applied in a specific model component, it is recommended that different measuring methods and/or thresholds be tested for best results to the extent the data are available. The application of density in various TPB model components is discussed further in Section 3.0.

Accessibility describes the ability of reaching destinations or activities. Accessibility is an important indicator in understanding the travel impedance or attractiveness among the TAZs. Accessibility has been proved a critical factor in various model components. Some models (such as the TPB model) use transit accessibility, which is defined as the number of jobs accessible in certain amounts of transit travel time in the vehicle availability model, based on the hypothesis that areas with better transit accessibility to jobs have lower needs in owning vehicles. Other potential accessibility measures include the amount of attractions accessible in certain amounts of walk time or highway travel time. However, all three of these formulations can be vulnerable to cliff effects as a slight change in travel time can result in crossing just under or just beyond the special threshold value and change the accessibility variable value dramatically. More frequently now, accessibility is defined as the composite (highway and transit) travel time and cost impedance. This value is readily available from network skims and calculated using the utility expressions present in logit-based mode choice models (i.e., the mode choice logsum value represents accessibility). This formulation does not suffer from cliff effects. The application of density in various TPB model components is discussed further in Section 3.0.

Other objective land use variables may be available for use. For example, mixed use can be measured as a composite variable, reflecting the distribution and balance between the number of jobs and residents. One example is the geometric mean[1] of the number of jobs and residents (with appropriate relative weights for each). However, it will need to be evaluated through the model estimation process whether using additional variables is beneficial to the overall fit.

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[1] The geometric mean of quantities A and B would be calculated as $\sqrt{A * B}$

## 2.2 Including Consideration of Nonmotorized Travel

TRB Special Report 288 documented that few medium-size MPOs and almost no small MPOs model nonmotorized trips, but more than half of the large MPOs include nonmotorized trips as part of their model set in some way. There are several reasons for incorporating nonmotorized travel in models: better modeling of mode choice, analysis of transportation demand management measures, analysis of alternative land-use patterns, and prediction of transit access. However, treatment of nonmotorized trips in the large MPO models varies widely. National Cooperative Highway Research Program (NCHRP) Report 535, Predicting Air Quality Effects of Traffic Flow Improvements, (2005) suggested that only some of the more advanced research models have attempted to fully model nonmotorized travel.

Land use policies, of course, influence nonmotorized travel, and an important reason for including treatment of nonmotorized travel in regional travel demand forecasting models is to improve the responsiveness of the model to land use policy changes. Indeed, modeling nonmotorized travel demand is generally most important in terms of providing forecasts of reduced motorized travel demand due to land use policies supporting of nonmotorized travel. That is, it is generally less important in terms of determining demand for nonmotorized facilities than for determining changes to motorized travel. This is because planned nonmotorized improvements generally follow from policy directives and a desire to support lower vehicle trip generation as well as higher transit use. For example, developers might be required to build sidewalks, include bicycle lanes, or include changing facilities in new developments as a matter of policy.

Some examples of nonmotorized models include:

- Full nonmotorized models, including trip generation, distribution, and assignment. For example, for the Central Artery/Tunnel project, a model focused on downtown Boston was developed as a submodel of the regional model system and a special pedestrian trip generation, distribution, and assignment model was developed along with a pedestrian network to review pedestrian impacts of project elements, including construction;

- Representation of nonmotorized travel through several steps of the regional travel model. For example, the Portland LUTRAQ model extended the preexisting nonmotorized modeling capabilities of the Portland model. Pedestrian environment variables and data were added to the model, which enabled more sophisticated auto ownership and mode choice forecasts. Portland Metro has also made subsequent enhancements to the regional model to include nonmotorized travel such that it is now fully integrated into the mode choice step (Rossi, 2000; Gliebe, 2009); and

- Representation and separation of nonmotorized trips before trip distribution. For example, the Delaware Valley Regional Planning Commission (DVRPC of Philadelphia) added nonmotorized trips to the trip generation model and then separated them out using a binary mode choice model prior to trip distribution[2]. This approach also was adopted for the Triangle Regional Model (TRM) covering Raleigh, Durham, and Chapel Hill in North Carolina. One potential problem with this approach is that improvements or deterioration in highway or transit travel times and costs have no impact on the share of trips that are forecast to be nonmotorized unless these variables are included. For example, transit improvement projects will decrease transit travel times, increase transit trips and decrease auto trips; but in a pre-mode choice model increased investments in autos or transit will have precisely zero impact on nonmotorized choices (Purvis, 2003). However, if the alternative is to ignore nonmotorized trips completely, this limitation seems to be something which can be recognized and tolerated in the shorter term.

Some MPOs are improving modeling of nonmotorized travel by introducing a high degree of spatial resolution into the model system since the measurement of small-scale accessibility is essential. One method that can be used for this purpose is to reduce zones to a size that can reflect meaningful walking distances between zones. TRB Special Report 288 recommends that walking distances should be no more than 0.5 mile between zone centroids in the urban portions of the modeling area, where the walking and bicycling modes are most likely to be used. Another method is to use geographic information systems to measure accessibility from a zone centroid or other variables that potentially influence the decision to walk and bike.

### *Triangle Regional Model Approach*

As outlined above, the current TRM estimates the share of trip productions that are made by nonmotorized modes with a set of binary choice models that are applied as part of the trip generation modeling effort. There are separate models for each trip purpose, developed based on home interview survey data collected in the mid-1990s.

There is currently an effort underway to recalibrate the TRM to bring nonmotorized travel through the mode choice step in the model process based on an activity-oriented home interview survey collected in 2006. A hold out sample from the home interview survey is being used to validate the models calibrated on the remainder of the home interview survey data. A key aspect of the work is to try incorporating additional objective independent variables in the existing model framework.

One task that has been performed as part of the TRM enhancement effort was to explore potential objective explanatory variables that could support enhanced nonmotorized models based on travel behavior research. Many existing implementations involve some sort of pedestrian environment factor (PEF)-type variable that often includes subjective measures. The TRM effort instead focused on using objective measures of pedestrian and bicycle friendliness.

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[2] Although this model was developed, the agency approach has been to instead use separate trip generation models for motorized and nonmotorized trips.

Table 2.1 provides a summary of identified potential variables. In order to operationalize these variables quantitatively at the appropriate level (e.g., zone, zone interchange), several transformations or translations are necessary. Other than impedance, most of these variables would be intended to be used at the zone level, but some might be calculated at larger than the zone level. For example, density or pedestrian environment variables might be better if measured based on a uniform area, say, within a one-mile radius of the centroid. This could help minimize the confounding effects of, for example, a dense zone surrounded by much less dense zones. This was actually done in the LUTRAQ work. Zone level measures can be too aggregate when zones are large. Sub-zone level variables similar to the walk percentages often used to declare transit walk access market size could be used to mitigate this issue. Some variables such as the accessibility variables would require zone-to-zone network skims, but the final values would be estimated at the zone level. As is clear from the table, the list of potential variables that can be used to estimate the nonmotorized model is large, and many are highly correlated with each other. The current effort is focusing on the most feasible candidates – variables for which data are available that can be forecasted and contribute to the predictive power of the model.

## 2.2 Improvements to Land Use Models

Although the overall focus of this task effort was on improving the regional travel model's sensitivity to land use policies and nonmotorized travel, it is important to recognize that there is a fundamental linkage between transportation infrastructure, services, and policies and land use development (location, type, and form). That is, transportation investment decisions clearly influence development choices, and the consequent effects of development choices, in turn, impact travel behavior.

All travel demand models have land use information as one of the fundamental inputs – the location, intensity, and type of future households and employment – though these may be represented with varying levels of detail or attributes. In addition to serving as important inputs to travel demand models, these land use forecasts also provide a general framework to guide growth and public infrastructure investment policies. Therefore, in considering improvements to the regional travel model's sensitivity to land use policies, we also gave consideration to how land use forecasts are developed.

Adopting an integrated transportation and land use modeling process would be a longer-term program. Therefore, discussion on land use modeling for travel demand modeling and policy evaluation purposes has been placed in Appendix A to this memorandum. Among the topics briefly covered are the state-of-the-practice in land use forecasting, an overview of major available land use models, and a summary of Metropolitan Planning Organization (MPO) efforts in land use model development, implementation, and integration with travel forecasting models.

## Table 2.1 Potential Variables for Development of Enhanced Nonmotorized Model

| Variable Type | Variable Descriptions |
|---|---|
| Land Use | **Density –** Enhanced and improved opportunities for walking and biking are typically found in places which have increased development density.<br>**Mixed-Use Development or Pedestrian-Oriented Development –** Increased opportunities for short-walk trips, especially non-work trips in compact mixed-use developments. Composite measures have been developed to measure the degree of mixed-use development.<br>**Proximity to Key Attractors –** Distance to key attractors such as major employers, universities, and schools which have improved support programs and amenities.<br>**Area Type/Urban Form Measures** – Propensity to engage in nonmotorized travel is likely related to area type and urban form measures although forecasting their presence may be challenging. |
| Roadway Characteristics | **Free-Flow Speeds and Number of Lanes –** Higher speeds generally decrease pedestrian and bicycle safety and discourage nonmotorized travel. Additional lanes increase street crossing distances and decrease the ease of pedestrian travel.<br>**Block Length and Street Density –** Higher network densities provide opportunities for more direct routing options for pedestrian and bike travel.<br>**Network Connectivity –** Street systems built in grid type patterns provide more opportunities for direct pathways between origins and destinations than streets built in more patterns that are more curvilinear and discontinuous.<br>**Grade –** Hilly terrain discourages walk and bike trips. |
| Intersection – Related Variables | **Pedestrian Signals and Crosswalks –** Increased sense of safety can promote walking and biking.<br>**Medians –** Provide safe haven for pedestrians at street crossings. |
| Nonmotorized Facilities | **Sidewalks, Bike Lanes, and Bike Paths –** Increased sense of secure travel ways can promote pedestrian and bicyclist activity.<br>**Pavement Markings/Signage –** Bike lanes and high-visibility signage may increase sense of safety and encourage bicyclists or pedestrians. |
| Characteristics of Population | **Age, Student Status, Household Composition –** Certain market segments may be more likely to travel by bicycle or on foot. |
| Accessibility | **Accessibility Measures –** The proximity of persons to activities may be quantified this way. Higher accessibility areas increase the likelihood of shorter trips to be nonmotorized. |
| Impedance | **Time or Distance –** Length of end-to-end trip is of interest – shorter trips are more likely to be nonmotorized. |

## ■ 3.0 Short-Term Enhancements

The TPB travel demand model follows the traditional four-step process: 1) trip generation, 2) trip distribution, 3) mode split, and 4) traffic assignment. The trip generation model is driven by a series of demographic submodels, including household size, household income, and vehicle availability. The vehicle availability choice model apportions households among vehicle availability levels based on household size, household income, area type, and transit accessibility. The current multinomial mode choice model is being replaced with a nested-logit mode choice model for the updated Version 2.3.

This section provides recommendations on near-term improvements which might be possible to incorporate in Version 2.3 of the model system. The objective of these recommendations is to enhance the model sensitivity to land use policies that allows for reasonable analysis and evaluation of key policy concerns (such as smart growth strategies, transit-oriented development, nonmotorized travel initiatives, etc.) within a practical framework in the absence of a land use model and an activity-based travel demand model in the near term.

### 3.1 Input Improvements

The TAZ is the smallest unit of geography in the travel demand model. Trips are generated at and distributed to each TAZ based on zonal land use attributes (density, area type, accessibility, etc.) and transportation conditions (travel time and costs). A finer TAZ system provides an opportunity to recognize the land use and transportation characteristics at a finer level, which can lead to more accurate and responsive forecasts to local policy changes. This is particularly true to the extent that the finer TAZ system is responding to forecasted changes in land use patterns, providing smaller zones in areas likely to have more nonmotorized travel (as is the case in the revised TPB TAZ system).

With a finer-level TAZ system, comes the need to develop a finer-level highway network. The improvements being made to conflate the highway network to the NAVTEQ centerline file will help improve the accuracy of the network and also help to enable the introduction of additional network elements to comport with the finer-level TAZ system. The finer-level TAZ and networks will help enable better representation of concentrated growth with more accurate density calculations; better depiction of street grids in transit-oriented developments; and better assessment of accessibility enhancements.

In addition to expanding the TAZ system as it currently is being developed, TPB also should incorporate the designated Regional Activity Centers and Clusters (RACC) into the TAZ system to ensure that the boundaries coincide with each other. The RACCs represent the areas with high concentrations of residential and/or employment and high potential for future growth. The distribution of these centers and clusters has great implications on both local and regional travel needs. A study, based on the recent TPB 2008 household travel survey, found that the household composition in the designated centers and clusters is significantly different from those in areas not designated as RACC. For example, RACCs generally have smaller households and fewer workers and automobiles per households than elsewhere in the region. The study also found that travel behavior in the RACCs was also quite different as compared to the rest of the region. In general, the RACC residents made more transit and walking trips and less vehicle miles traveled (VMT) per household than people living elsewhere in the region (TPB, 2008b). Whether a TAZ is within the designated RACC could be a strong indicator in travel demand analysis.

Although a RACC Indicator shows promise based on these preliminary household travel survey findings, it should be noted that it is always preferable to use a fully objective measure in the model rather than simply a designation since it is not the designation which is leading to the alternative household characteristics and travel behavior, but rather some other factors inherent to these areas. It is recommended that effort be made to determine if alternative, fully objective measures of pedestrian and transit supportive land use could be used to achieve similar differentiation of household composition and travel behavior. This would avoid the challenge of less-developed RACCs receiving similar treatment to more-developed RACCs and other potential unintended bias due to subjective treatment. It is likely that such a selected objective measure(s) would be generally correlated with RACC designations, but might designate additional locations as having similar household and travel characteristics. Subject to data availability, different density measures or accessibility measures as described in Section 2.0 could be employed in this exploration.

## 3.2 Model Component Improvements

Land use activity can be generally incorporated in a number of submodels, utilizing either density or accessibility measures. The sections below provide an overview of these measures, and how they could be utilized in the various submodels. It should be noted that that incorporating density and accessibility measures will require reestimation and recalibration efforts to determine the most suitable model specifications, as well as to ensure certain degree of confidence in the model's ability to reasonably replicate the observed travel behavior. The recently completed 2007 through 2008 household travel survey provides a good source of data for the above needs. Supplemental data sources for validation purpose may include Census, ACS, traffic counts, etc.

### *Household Characteristics Models*

The trip generation step of the TPB model is driven by a series of demographic submodels, including household size, household income, and vehicle availability. It is recommended that explorations for improving the representation of land use policies and nonmotorized travel in the trip generation step begin with these demographic submodels. This is partly due to findings in the literature that household characteristics in transit-oriented and other concentrated developments tend to differ from ordinary development household characteristics. To the extent these differences are then reflected in the demographic submodels and explain trip generations rates, the need to alter (or complicate) the trip generation models themselves is reduced.

Among the demographic submodels to be reviewed is the TPB vehicle availability model. It is a choice model that determines household shares among auto ownership levels (zero car, one car, two cars, and three or more cars) based on zonal household size, household income level, area type, and employment accessibility. Possible improvements to the vehicle availability model include: 1) adding a RACC indicator, and/or 2) introducing a density variable. Other land use related variables could also be considered, such as housing type, to the extent data are available for both base and forecast year usage.

Based on the preliminary household travel survey findings cited in Section 3.1, adding one indicator in the vehicle availability choice model representing whether the TAZ belongs to one RACC may lead to more accurate estimate in auto ownership, and may also improve the model sensitivity to land use policies pertaining RACC and non-RACC areas. The indicator could be as simple as whether one TAZ falls in one of the RACCs; it could be more complex that takes into account the six different types of RACCs (DC Core, Mixed-Use Centers, Employment Centers, Suburban Employment Centers, and Emerging Employment Centers); or it could be based on an objective measure such as density. Density could be a quite satisfactory indicator. In general, areas with higher density experience lower auto ownership and higher shares of transit and nonmotorized travel. Experimental tests in different specifications will need to be performed to determine the best suitable indicator or indicators.

### *Trip Generation*

In the TPB model, zonal-level trip production is determined utilizing cross-classification trip rates stratified by household size, income level, and vehicle availability for each purpose. The drawback of this cross-classification model lies on its fixed, aggregate classification that is insensitive to land use attributes. Without engaging in an activity-based modeling structure, possible short-term improvements to the trip generation model can be accomplished by introducing further market segments in the classification using either one or a combination of the following indicators: RACC indicator, density, area type, and accessibility. As with the demographic submodel improvement, extensive testing should be conducted to determine the best specification.

### *Nonmotorized Travel*

The TPB model addresses nonmotorized travel for the home-based work (HBW) trip purpose only. In the existing nonmotorized model, travel is obtained as a proportion of HBW trips, stratified by area type. As more and more land use policies and programs emphasize the importance of smart growth, neotraditional neighborhood, and mixed land uses, this existing model may not provide sufficient information on motorized trip reduction due to increased nonmotorized travel. This may be particularly true since, in general, there are more non-work nonmotorized trips made than work purpose nonmotorized trips.

One approach is to extend the current nonmotorized model approach to other trip purposes – apportion the share of nonmotorized travel from the total production based on area type. The model can be extended further by introducing other segments, such as density, accessibility, and RACC indicator (as discussed above), given that these factors show promise based on the preliminary household travel survey analysis. This approach would represent an improvement over the current model in that it recognizes the significance of nonmotorized travel for other purposes other than HBW; and it would take into account local land use characteristics. However, nonmotorized travel would still be estimated based on relatively "fixed" rates/ proportions and would not be sensitive to small changes in the land use variables.

Another approach is to implement a pre-trip distribution model, much as the existing TRM approach, that predicts the binary choice between motorized and nonmotorized modes of travel based on socioeconomic characteristics, local land use attributes, and transportation conditions. The methodology is similar to a regular mode choice model that predicts mode split among motorized modes. Important variables that need to be explored in the model include income, area type, density, transit and walk accessibility, RACC indicator, and other zonal attributes that may contribute to pedestrian/cycling environment. Again, extensive testing needs to be performed to determine the best model specification, with special attention paid to the correlation among the variables.

In the shorter term, it is recommended that one of the two above methods be used. In the longer term, consideration should be given to extending the treatment of nonmotorized travel through the trip distribution and mode choice model steps.

## ■ 4.0 Longer-Term Enhancements

The previous section discussed short-term approaches to improving the model's sensitivity to land use policies and nonmotorized travel. The purpose of this section is to point out a few directions that are worthy of attention for future consideration when and if resources become available in the longer term.

### 4.1 Travel Demand Model

#### *Special Purpose Models*

It might be feasible to introduce special purpose models in RACC areas for pedestrian modeling in the manner provided as an example from the Central Artery/Tunnel project. That is, to develop nonmotorized trip generation, trip distribution, and trip assignment models for special purpose evaluations. This might be a priority for reviewing pedestrian circulation or maintenance of traffic issues in these designated areas. The Central Artery/Tunnel model was developed to help plan pedestrian facilities associated with the complete redesign of the surface street system in the corridor, as well as during construction, when lots of streets or street crossings were closed temporarily. For major projects, such an extensive effort could be beneficial. For more common planning purposes, the benefits may not warrant such a treatment.

### Longer-Term Modeling Framework

In an earlier technical memorandum, Cambridge Systematics suggested that selected major longer term improvements be guided by a more-fundamental decision as to whether TPB would pursue development of an activity based modeling framework. Such a decision would guide the mechanics of the further enhancements (but not necessarily the type of enhancements). It is known that TPB plans to explore development of an activity based modeling framework further in the coming year. For some activity-based modeling implementations, such as in Sacramento and that planned in Houston, parcel-based modeling has been used, though it does require additional data. Once further plans are made in regard to the activity-based modeling framework, decisions about the timing of further model improvements should be revisited.

### Destination Choice Model

Although the model estimation would differ depending on whether an activity based modeling framework is adopted or a trip based framework is maintained, the desirability of developing a destination choice model to replace the gravity-based trip distribution model remains a high-priority longer term recommendation. A destination choice model predicts the destination TAZ of a trip based on various zonal attributes for each trip purpose. A destination choice model is superior to gravity-based models in that:

- The utility-based structure provides more flexible extension of gravity-based models;
- There is explicit representation of various zonal attributes in the destination choice utility expression;
- The model is linked with mode choice logsum, and simultaneously considers impedance and attractions; and
- Model estimation is performed at disaggregate level.

A destination choice model provides a platform to introduce land use variables, therefore enhancing the sensitivity of the TPB model to land use changes. A destination choice model usually employs a multinomial logit structure with all TAZs as alternative choices. If a destination choice model is to be applied to nonmotorized travel, then the alternative TAZs are often constrained by distance from the origin TAZ. Density measures and/or the RACC indicator, as discussed in the previous sections, could be examined as variables to be used in the destination choice model. Accessibility measures in destination choice models are usually defined as the generalized cost impedance. Detailed definitions and model specification need to be determined through various tests based on the household travel survey data.

### Time of Day Model

Peak spreading can be one effect of concentrated land use policies which lead to higher levels of congestion in the vicinity approaching the designated growth zones. Some motorists begin their trips that would otherwise use congested corridors to reach these destinations, either earlier or later to save travel time. The current model does not include a time of day model. Such a model could be introduced in the longer term. The formulation and estimation of such a model would depend upon whether an activity-based or trip-based model framework was being used. Therefore, it has been previously recommended that development of a time of day model wait for the framework decision to be made. However, it is recommended that TPB work with the area jurisdictions to begin to put methods into place to enable the collection of the traffic count data on a coordinated basis which would be necessary for calibration and estimation of such a model.

### *Expanded Treatment of Nonmotorized Trips*

As noted under the short-term recommendations, in the longer-term it could be desirable to extend the treatment of nonmotorized trips into the trip distribution and mode choice steps of the model. The primary benefit of such an expanded treatment is that the level of nonmotorized travel would have sensitivity to travel time changes in other modes of travel.

## 4.2 Land Use Database Enhancement

To the extent not already available, it is recommended that attention be given to developing and/or enhancing the land use database (for both existing and forecasted land use). In addition to the summary land use measures used in the current modeling, an enhanced database should include additional variables that would facilitate the calculation of density using the various methods described in Section 2.0 (e.g., net density) and permit the exploration of additional land use related variables in model estimation (e.g., housing type). Such an enhanced land use database would be resident in a geographic information system (GIS) and could benefit various planning studies and analysis, including housing studies, pricing strategies, economic development initiatives, transit service evaluation, nonmotorized travel analysis, etc. It could also ease the effort for developing a land use model in the long run.

## 4.3 Land Use Model Development

A possible long-term goal for TPB is to pursue adoption of a formal land use model. Appendix A discusses developments in this area and suggests that such tools have proven to be a useful way to facilitate a wide range of policy and program discussions. For the Washington, D.C. metropolitan region, the designation of RACCs may be an effective approach to guide and formulate the regional land use development pattern. A formal land use model could further contribute to the program by providing a scientific formula and detailed criteria for designation of new or existing growth centers.

Most of the concerns related to land use model development and implementation have to do with resource and data needs. Experience from other MPOs indicates that successful land use model development requires technical and financial commitment at all levels. Almost all land use model development relies on consultant work and needs extensive disaggregate data for model calibration.

Understanding the political and technical environment of the region and establishing collaboration among all members and relevant agencies are the first and key steps towards land use model development, because land use issues are political, multidisciplinary, and multiagency in nature. The understanding and collaboration set up the foundation of, as well as the requirements for, the regional model, based on which the best technical approaches to addressing those needs should be determined. The next key step is to compile and maintain/update all the data that are needed to support the model development and application. Last, but not least, taking incremental steps is almost always the best approach to developing complex models, such as land use models. Coordinated with staff and financial constraints and data availability, phasing can be applied in various aspects, such as modeling area coverage, land use zone size, submodel components, and visualization capabilities.

## ■ 5.0 Next Steps

This memorandum provides a background picture of current practice in the modeling process dealing with land use issues; and presented shorter- and longer-range approaches for TPB to improve its modeling capability in responding to the increasing needs to address various land use and transportation policy concerns. In the near term, the TPB should focus on the shorter term practical improvements while keeping in mind possible paths forward in the longer term, especially as progress is made in determining a vision for the model framework beyond Version 2.3. Special attention should be paid to discerning measures which can help account for the differences in household characteristics and travel behavior observed in the RACC areas in the recent household travel survey.

# ■ A.0 Review of Land Use Modeling

The overall focus of this task effort was on improving the regional travel model's sensitivity to land use policies and nonmotorized travel. However, it is important to recognize that there is a fundamental linkage between transportation infrastructure, services, and policies and land use development (location, type, and form). That is, transportation investment decisions clearly influence development choices, and the consequent effects of development choices, in turn, impact travel behavior.

All travel demand models have land use information as one of the fundamental inputs – the location, intensity, and type of future households and employment – though these may be represented with varying levels of detail or attributes. In addition to serving as important inputs to travel demand models, land use forecasts also provide a general framework to guide growth and public infrastructure investment policies. Therefore, in considering improvements to the regional travel model's sensitivity to land use policies, we also gave consideration to how land use forecasts are developed.

This Appendix presents a brief discussion on the state-of-the-practice in land use forecasting, an overview of major available land use models, and a summary of Metropolitan Planning Organization (MPO) efforts in land use model development, implementation, and integration with travel forecasting models.

## A.1 Traditional Land Use Forecasting Approach

A variety of approaches are used by MPOs to develop land use forecasts, including manual and model-based methods. The current state-of-the-practice in land use forecasting associated with travel demand modeling is to employ demographic models that produce population and employment projections at an aggregate level (usually county and subregional level), and then to perform manual allocations to arrive at growth projections at a TAZ level. The allocation process can be a combination of bottom-up and top-down approaches depending on the level of certainty about plans in different TAZs or TAZ groups. Sometimes it can take several rounds to reach consensus among all the relevant agencies. Although this process serves the need to have land use inputs for the travel demand models, it does not provide a mechanism that enables explicit representation of dynamic urban forms or the interaction between transportation and land use. That is, the traditional method generally is not sensitive to local policy initiatives.

Limitations of the traditional land use forecasting method may include the following:

- The scenarios are often simplified (lack of detailed characteristics of population and employment) and unrealistic, and are often internally inconsistent because of arbitrary scenario hypotheses;
- The scenarios are often inconsistent with the transportation system because of the lack of feedback between land use and transportation system;

- The method can maintain separation between land use planning and transportation planning disciplines;
- It cannot adequately address the impacts of transportation policies on the land use pattern, and vice versa;
- It relies heavily on personal/local knowledge and experience (usually nontransferable and nonreplicable) and often lacks a robust methodology and scientific base/tool for debating and discussion;
- It usually operates in one direction, from land use forecasts to travel demand models, without a platform to facilitate the representation of the interactions between the transportation system and land use;
- It leads to an inability to evaluate policies required to achieve optimal land use patterns; these include policies such as smart growth, tax reductions, cost sharing, and land banking; and
- It leads to an inability to assess the regional impact of proposed local jurisdiction land use policies (TMIP, 2008).

## A.2 Advanced Land Use Modeling Approach

Realizing the limitations of the traditional forecasting approaches and the importance of incorporating land use-transportation connections in the planning process, many metropolitan planning organizations (MPOs) are moving towards integrating the travel demand model with a formal land use model, with a few successful implementations now demonstrated nationwide. The success of these programs relies on the ability to assess and quantify the impacts and effectiveness of these policies and strategies, i.e., the analytical capability to estimate the impacts of land use on the transportation system, and vice-versa.

The promise of using an integrated modeling platform can be summarized as follows:

- **Technical Capability –** With the aid of a land use model, more accurate and realistic land use data (population, household, employment) can be provided to the travel demand model, which leads to better prediction of the travel patterns. Usually a travel demand model considers short-term travel choices, such as destination/route choice, time-of-day choice, mode choice, etc., assuming that the socioeconomic structure of the region remains the same. However, under dynamic urban contexts, people often make long-term choices on household locations or employment locations, which have implications on both land use and transportation system. These effects could not be captured by a travel demand model alone. An integrated land use-transportation model system could completely represent both short-and long-term responses to policy-level decisions.

- **Policy Sensitivity –** Transportation programs affect land use directly by dedicating certain amounts of land for transportation facilities, and indirectly by improving the accessibility to a certain area. On the other hand, land use or development policies directly influence travel needs and viable travel mode alternatives. An integrated land use model provides a platform that enables planners and decision-makers to explore the likely consequences of various policies (such as infrastructure investment, congestion pricing, variable tolling, housing, zoning, etc.) by providing a means to trace the complex chain of spatial processes (travel, auto ownership, location choice, land development, etc.) that respond over time to these policies (Miller, 2008).

- **Integrated Approach –** The link between land use and transportation is critically related to a region's economic health and its communities' quality of life. Many transportation-related problems may have their origins and, perhaps, solutions in land use policy. Without considering transportation and land use policy as a whole, the individual transportation or land use models may overestimate or underestimate some of the system responses to policies. Thus, the regional planning process could benefit from an integrated analysis of land use and transportation policies together. The promise of such an approach is that it could enable local agencies to make informed decisions provided with better guidance on future growth.

A broad range of policy analysis can be achieved through an advanced land use model or an integrated transportation-land use model, which may include the following:

- **Evaluate Policies, Plans, and Programs –** provide visual and quantitative capabilities in growth scenario planning, evaluate the economic implications of transportation investments, assess the effectiveness of strategies in achieving various goals, assess potential impacts and benefits of various policies and programs, and provide the analysis capability of evaluating the long-term impacts.

- **Transportation Analysis –** assess potential cumulative and long-term impacts of transportation projects, estimates traveler responses to various travel demand management strategies, and analyzes induced demand.

- **Land Use Analysis –** assess the effects of transportation system on land uses, and vice-versa over time; predict long-term choices, such as residential employment and development location choices; and analyzes the impacts and benefits of smart growth strategies, etc.

## A.3 Common Land Use Models

This section provides an overview of the most widely used land use models.

### *DRAM/EMPAL – Disaggregate Residential Allocation Model/Employment Allocation Model*

DRAM/EMPAL was developed by Dr. Stephen Putman during the early 1970s, and is the most widely applied land use model in the nation. The Disaggregated Residential

Allocation Model (DRAM) and Employment Allocation Model (EMPAL) are based on the principles of the Lowry model that was developed in 1964. The Lowry model combines the economic base multiplier model and the gravity model, which allocates population and employment to a zone based on its attractiveness, given known locations of the base employment and the transportation conditions. DRAM/EMPAL expands the Lowry model by introducing constraints into the allocation model. It has been continuously implemented by various metropolitan areas because it is robust, easy-to-calibrate, and the required data are generally available. Because of its focus on allocation at aggregate level, its weakness is quite obvious as well – sensitivity analysis is not possible.

S.H. Putman Associates later developed a software package embedded in a GIS environment: METROPILUS (Metropolitan Integrated Land Use System). To provide a user friendly land use model for small- and medium-size Metropolitan Planning Organizations (MPOs), Federal Highway Administration (FHWA) sponsored the development of TELUM (Transportation Economic and Land Use Models), which is a derivative of the METROPILUS modeling package. TELUM includes a series of modules in model input, calibration, and application, and its integrated GIS module allows mapping of input/output spatial data. Remaining resident within TELUM are the DRAM and EMPAL models.

Dr. Kara Kockelman pursued the development of G-LUM, an open-source, freely-available MATLAB implementation of a gravity-based land use model encompassing employment allocation, residential allocation, and land use consumption submodels. The model is available for download at http://www.ce.utexas.edu/prof/kockelman/ and an over of lessons learned in developing and applying the model are provided via a presentation made to the Association of Metropolitan Planning Organizations available for download at http://www.ampo.org/assets/773_kockelmanlessonslearnedin.pdf

### *UrbanSim*

UrbanSim was developed more recently. It is an open-source land use model developed by a research group at the University of Washington, which was led by Professor Paul Waddell. The model comprises four major components: 1) a residential location model; 2) an employment location model; 3) a developer model; and 4) a land price model. The first three models simulate the location choices of the principal agents (households, employers, and developers). Their interactions with real estate market are reflected through the land price model. UrbanSim's behavioral approach, which clearly identifies the principal agents of the urban dynamics and models their actions, is preferred to the "black-box" approach used in other land use models. UrbanSim also allows for direct user inputs of policies and assumptions. Detailed information about UrbanSim can be found at the models' web site http://www.urbansim.org/.

### *Production, Exchange, Consumption Allocation System (PECAS)*

PECAS is also a more-recently developed land use model. It was developed by Dr. John Douglas Hunt at HBA Specto Inc. PECAS has its roots on spatial input output theory, which is designed to track changes in various sectors of the economy responding to activities in one or more sectors by establishing a static equilibrium solution among all sectors. Monetary flows generated from economic exchanges are converted to movements of goods and people. PECAS predicts flow of goods, services, labor, and space across land use zones using three-level nested logit model: the first level determines the location choice of activities; the mid-level choice predicts the quantity of production/consumption for each commodity (goods, services, labor, and floorspace); and the last level decides where to exchange those commodities that implies travel or freight shipment. The uniqueness of PECAS lies on its explicit representation of economic exchanges and the ability to simulate goods movement; however, it also requires inputs from an exogenous economic input/output model. More information about PECAS can be found at http://hbaspecto.com/.

### *MetroScope*

Portland Metro's, MetroScope is worth mentioning here because it is one of the very few land use models in use that was developed entirely in-house. This modeling effort represents an incremental evolving process starting in 1996. It started out as a one-zone residential model in a spreadsheet model written in Visual Basic, and was completely updated to a free-standing land use model in by 2006 that covers 6.5 counties and 2029 traffic analysis zones (TAZ). MetroScope includes a Geographic Information System (GIS) interface that allows the users to view and manipulate data. The latest version has two main components: a residential location choice model and job location choice model. Inputs/components include a household demand forecast, job demand forecast, travel time/accessibility forecast (i.e., travel demand model), and land supply/capacity data (e.g., vacant land, refill supply, etc.). Feedback loops are provided among the components to permit the interactions to be represented in the forecasting framework (Conder, 2008).

## A.4 MPO Efforts in Land Use Model Development/Implementation

This section presents a summary of current practices among a range of MPOs. The information provided here is mainly summarized from an intensive review (including a workshop) conducted at the New York Metropolitan Transportation Council (NYMTC), a study performed by Meyers et al. (2006) for the Atlanta Regional Commission (ARC), and information from various MPO documents and websites.

- **Baltimore Metropolitan Council (BMC)** covers seven jurisdictions with more than 2.5 million populations and more than 1.5 million employments. The BMC has worked for many years on land use issues. In the 1990s, it established a land use subcommittee that ultimately led to the deployment of the TRANUS model in 2003. This was not considered a successful model and the BMC switched to deploying the PECAS model beginning in 2005.

- **Denver Regional Council of Government (DRCOG)** covers 12 jurisdictions with about 2.7 million people. DRCOG has been using DRAM/EMPAL for many years. An effort to move towards an integrated regional model that incorporates both travel demand model and land use model is planned.

- **Houston-Galveston Area Council (HGAC)** serves the 13-county Gulf Coast Planning region of Texas that covers 12,500 square miles with more than 5.7 million people. HGAC implemented UrbanSim in 2003 with two successful horizon scenarios (2025 and 2035 RTP). HGAC is currently developing an updated model based on finer level (parcel-level) simulations.

- **Portland Metro Council (Metro)** serves three counties and 25 cities in the Portland region that covers 3,700 square miles with more than 1.4 million people. Unlike most other metropolitan areas, Metro developed its own land use model – MetroScope – in-house, rather than adapting an existing land use model. The modeling efforts have been an incremental process over a decade, starting from a spreadsheet to the latest updated, free-standing model that includes its own travel demand assignment model.

- **Puget Sound Regional Council (PSRC)** covers four counties with more than 3.4 million people. It has been using DRAM/EMPAL for many years, and currently is testing UrbanSim for deployment.

- **Sacramento Area Council of Government (SACOG)** serves six counties in the Sacramento region that covers 6,700 square miles with about 2.2 million people. Its development of a PECAS land use model is nearly complete

- **San Diego Association of Governments (SANDAG)** serves as the forum for regional decision-making for the 18 cities and county member governments. A PECAS model implementation is currently underway to replace the Urban Development Model as its small-area forecasting tool.

- **Wasatch Front Regional Council** serves as the MPO for the Salt Lake City region. The Federal Highway Administration Travel Model Improvement Program supported an initial application of the Urbansim model to the region.

The ARC review included BMC, DRCOG, HGAC, Metro, PSRC, and SACOG. Table A.1 through Table A.6 present a summary of the modeling efforts at these MPOs from various perspectives including staff and budget resource requirements, application frequency, type of model, model performance and application, and data requirements. Most MPOs surveyed for the ARC study stated that their land use models are not directly linked with conformity analysis. The land use forecasts are used to support transportation plans.

In HGAC, land use forecasts and travel demand forecasts are generated in parallel and independently by separate departments. The land use forecast uses travel time skims and accessibility information from the transportation model as generated in the most recent run of the long-range travel demand forecast. Likewise, when a long-range travel demand forecast is produced, it uses land use inputs that depend on forecast year, but as generated in the most recent run of the long-range land use forecast.

In SACOG, the land use model and travel demand model run iteratively. Draft land use forecasts are developed based on the most recent transportation skims first to begin the process. The official land use forecasts are not adopted until the transportation plan is adopted because the land use might change depending on different transportation investments.

### Table A.1 Land Use Modeling Staff and Budget

| MPO | Land Use Model Development | Land Use Model Unit |
|---|---|---|
| BMC | $0.3M (including staff time, but not including data collection and preparation) | 2.5 FTE; 5 percent of total budget |
| DRCOG | | 2 FTE; 5 percent of total budget |
| HGAC | | 3 FTE; 5 percent of total budget |
| METRO | 0.2 FTE 4 years | 0.8 FTE for model operation and upgrade; 3.8 FTE $1.5M for the entire group responsible for regional forecasting, land use modeling, data analysis, and systems development services |
| PSRC | $1.3M 2 FTE ($200K for in-house data preparation) | 20 FTE for the entire data analysis capability |
| SACOG | | 7 FTE; $2M-$3M (20-30 percent of total budget) for the entire research and analysis group |

### Table A.2 Land Use Forecasting Frequency

| MPO | How Often are Land Use Forecasts Produced |
|---|---|
| BMC | Every year, for conformity analysis |
| DRCOG | Database updated every year; forecasts fully updated every 2-3 years corresponding to transportation plan update |
| HGAC | Synchronized with the transportation planning cycle; done 1 year prior to the planning analysis |
| METRO | Official forecasts for RTP update every 5 years; 2 to 10 application runs per year for variety of planning analysis |
| PSRC | Fully updated every 3-4 years |
| SACOG | Three-year cycle |

## Table A.3 Type of Land Use Model in Use

| MPO | Previous Model | Current Model |
|---|---|---|
| BMC | TRANUS (2003) | PECAS (development started in 2005) |
| DRCOG | DRAM/EMPAL | Moving to UrbanSim |
| HGAC | DRAM/EMPAL | UrbanSim(is use 2003) |
| METRO | | MetroScope (latest update in 2005) |
| PSRC | DRAM/EMPAL | UrbanSim |
| SACOG | DRAM/EMPAL and MEPLAN | PECAS |

## Table A.4. Land Use Model Applications

| MPO | Purposes Other Than Transportation Planning |
|---|---|
| BMC | Reservoir planning; emergency management |
| DRCOG | Regional water resource planning |
| HGAC | Aging, FEMA, flood control, landfill sitting, and job training |
| METRO | Urban growth boundary planning, central facilities planning (fire stations, health facilities, schools, etc.), affordable housing, water/sewer demand forecasting, regional land use planning policy, economic development planning |
| PSRC | Local jurisdictions use forecasts to comply with State's growth management mandates |
| SACOG | Affordable housing (forecast-year 2011); Air Quality Management District for the SIP update<br>Flood protection planning of the agency |

## Table A.5 Forecasting Control Values

| MPO | Control | Data Source |
|---|---|---|
| BMC | No control | Simply the sum of the individual community members' expected growth |
| DRCOG | Region level | From economic consultant reviewed by panel |
| HGAC | County level | An econometric model; switched to a simpler demographic model |
| METRO | Region level | A regional economic model |
| PSRC | Region level | An econometric model |
| SACOG | Region level | The Department of Finance and an independent consultant study |

## Table A.6 Data Requirements

| MPO | Major Inputs | Data Sources |
|---|---|---|
| BMC | Income, non-institutional group quartiles, number of workers, auto ownership, a household matrix etc. | Property appraisal, building permit, and zoning databases. |
| DRCOG | Household and employment points, income, household price, roadway network. | Census data are used for household information. ES202 data are used for employment data, CTPP data, roadway network, estimates of households, and employment by TAZ from local government are used as "capacity thresholds" for the TAZs. |
| HGAC | Existing land uses and the developability/ redevelopability of land, highway skims, a base year synthetic population, transport accessibility, as well as the following base-year information for each grid cell: employment by sector, housing units and nonresidential square footage, land value, improvement value, and land use category. | |
| METRO | The stock of land resources both vacant and refill by zone class, the amount of land to be added to the UGB, the transportation supply schedule, zone changes, housing and nonresidential real estate stock and transportation system, housing and location choice and price data, nonresidential location and choice data, initial land value, and construction cost data. | Census PUMAs, Survey of Consumer Expenditures, Metro Regional Land Information System (RLIS). It takes usually two to six months, including parameter estimation and sensitivity testing. This represents about 15-20 percent of the land use modeling effort. Local agencies review input data on capacity and update it with latest plan changes. They also review assumptions and redevelopment and infill potential. |
| PSRC | Households, population, employment, developable land, transportation system performance, etc. | Assessor's data for parcels and buildings, including square feet and attribute data.<br>Long-range comprehensive plan information.<br>A GIS overlay for environmental constraints indicates areas that need to be avoided.<br>Demographic tables, including jobs and households (which come from the synthesis module using census and PUMS data). It takes about 1 ½ years to clean up the input data. |
| SACOG | Households, population, employment, information from local plan, an environmental layer on their GIS system, and assessor's data. | |

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CAMBRIDGE
SYSTEMATICS

# Recommendations on Feedback Convergence Methods

# task memorandum

*prepared for*

**National Capital Region Transportation Planning Board**

*prepared by*

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*November 20, 2009*

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# Recommendations on Feedback Convergence Methods

## ■ 1.0 Introduction

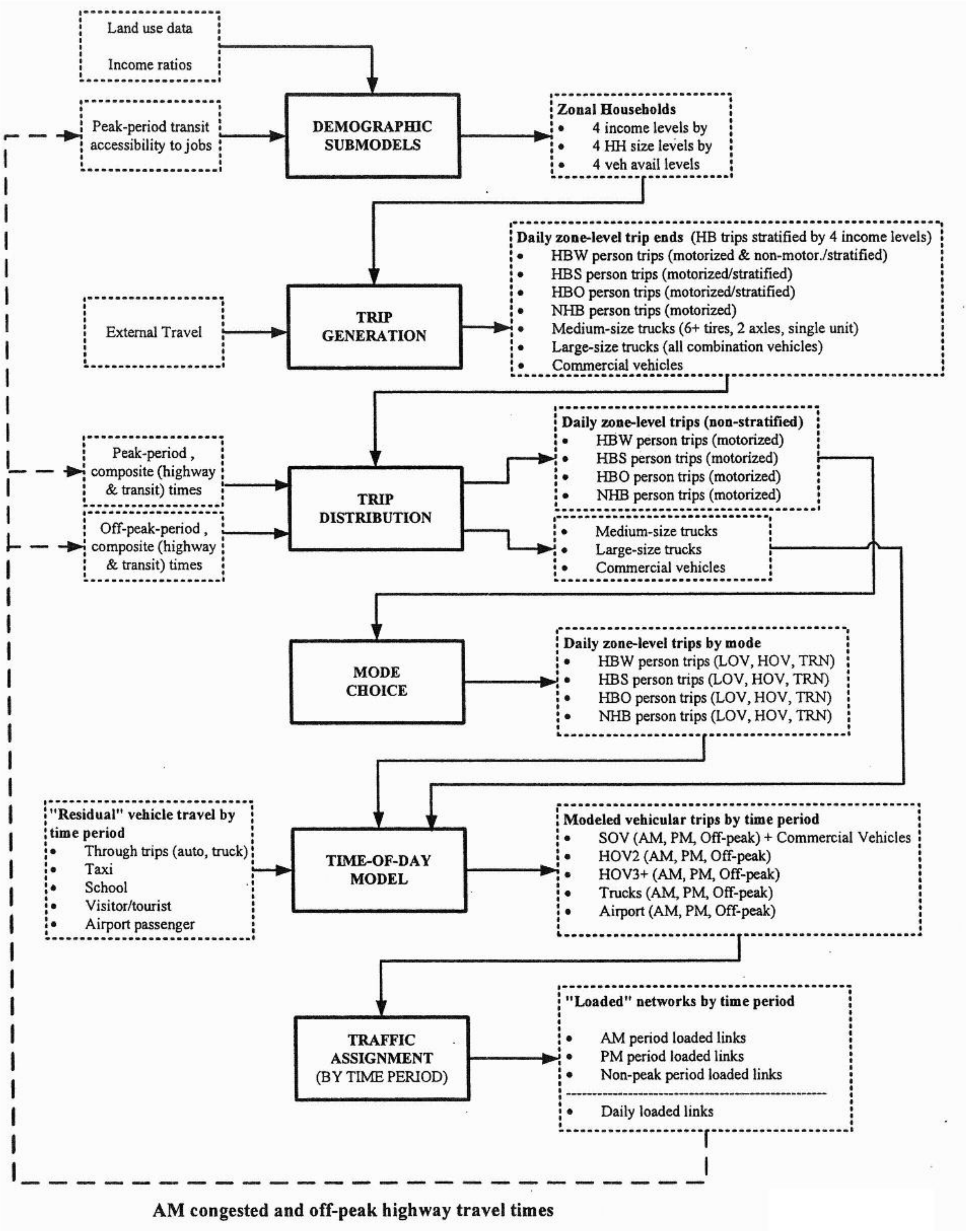
The currently adopted TPB Version 2.2 travel demand forecast model includes a speed feedback process that has evolved over the years. The existing model application involves an initial four-step execution using a set of initial highway speeds based on facility and area types. These basic speeds are used in the skims for the trip distribution model with a fixed transit percentage in place of a mode choice step. This initial procedure is known as the "pump prime" execution of the model chain. It provides a warm start to later assignment application.

Following the initial pump prime execution, the entire model chain is run through six iterations. An overview of the model process is provided in Figure 1. Each series of runs uses the results of the previous run. The loaded network is used to develop highway speeds which are skimmed and returned for use in the beginning of the model chain. The speeds are a function of the loaded highway assignment link flows, which are an average of the previous runs. This averaging is based on the application of a method of successive averages (MSA). The goal of the MSA procedure is to achieve a convergent highway assignment faster while reducing the number of required iterations. The model process as a whole has a substantial feedback looping process.

The full execution of the Version 2.2 model currently takes longer than a day given the need for multiple model runs (e.g., base and conformity) and the long execution time for the highway assignment step. The additional improvements in the upcoming Version 2.3 model, including a nested logit mode choice model and a greater number of zones, will further increase the run time. TPB staff has voiced concern about this increase; the goal of the TPB staff previously had been to have the run time down to an overnight period, where the model could be set to run at the end of the work day and results would be ready the following morning.

Possible strategies for streamlining the process and offsetting the increase in run time include reducing the number of speed feedback iterations undertaken in a single application and decreasing the run time for the highway assignment. The convergence of the highway assignment algorithm and the speed feedback are directly linked. If the assignment can converge faster and more accurately, then the speeds will hopefully be more accurate and the number of feedback loops required for convergence reduced.

**Figure 1. TPB Version 2.2 Model Structure**



Source: National Capital Region Transportation Planning Board, *TPB Travel Forecasting Model Version 2.2 Specification, Validation, and User's Guide*, March 1, 2009, Washington, D.C.

Reducing the number of feedback iterations raises the following questions:

- What is the acceptable practice for attaining convergence in the context of the TPB travel demand forecasting model process as well as for other large congested urban areas?
- What are possible metrics that could be considered in determining highway assignment convergence and speed feedback convergence?

The goal of this memorandum is to present relevant strategies for TPB staff to evaluate and provide guidance in the future development of the Version 2.3 model. These strategies focus on the convergence of the highway assignment and the dependent relationship of the speed feedback loops to highway assignment and the entire model chain. Also addressed are possible metrics for convergence in both the highway assignment and the speed feedback process. Additionally, where relevant, experiences from other MPOs and state of the practice on the feedback are cited.

# ■ 2.0 Limited Strategies for Run Time Improvements

The main purpose of this memorandum is to examine ways that the current TPB Version 2.2 and the developing Version 2.3 travel demand forecast models can be improved with respect to run time and the relationship to feedback and assignment convergence. However, it is worth noting other areas of the process that also can address the objective of shortening the long model execution time. The following topic areas warrant discussion:

- Removing feedback to demographic submodels;
- Changing HOV skimming method for HOT facilities; and
- Removing the transit constraint.

## 2.1 Removing Feedback to Demographic Submodels

As currently developed, the TPB Version 2.2 model does not dynamically link bus speeds to automobile speeds on the same links. Instead, transit travel in-vehicle times are hard-coded into the line files. In proper use of the model, transit speeds should be generally checked to ensure against unrealistic resulting assumptions, but vehicle congestion does not directly and dynamically impact transit in-vehicle speeds. Only the drive access component of the transit time between zonal pairs is dynamically affected by the recycled highway speeds. As a result, the measure of peak-period transit accessibility in the demographic submodels currently would not be anticipated to change much through the feedback process.

The approach of providing a feedback loop to land use models (or demographic submodels) is one used by other MPOs. For example, PSRC has a feedback loop to its land use model which in turn leads to impacts on trip generation. The Sacramento area's

SACMET model uses time and cost skims from the final network as input to its automobile ownership model, again resulting in changes in the model output. In both of these cases, the models have congestion sensitivity with respect to transit travel times.

A question then arises as to whether it is worth the processing time required to continue taking the TPB feedback loop to the demographic submodels in the short term, since transit in-vehicle travel times do not vary dynamically with highway congestion in the Version 2.2 or Version 2.3 TPB models. The drive access component of transit travel time would change due to changes in highway congestion, but this represents a smaller component of the overall transit travel time. That is, changing the feedback loop to return to the trip distribution step rather than to the demographic submodel step likely would have little-to-no impact to the model results, but lead to a shortened run time for the model set.

This strategy to improve the total model run time is recommended only as a short-term strategy. It is recommended that TPB staff quantitatively evaluate the impacts of the speed feedback loop on the trip generation step of the model by analyzing the amount of change in the results without this feedback process. That is, there is a need to determine how the transit accessibility measure (which is a composite of transit and highway skims) is impacted by not including the feedback loop to the demographic submodels. In the longer-term, model improvement might include calibrating the model set to work with transit travel time coding that is directly based on the underlying highway link travel times. The San Diego regional travel demand forecast model uses a bus speed model linked to the highway network. A review of the model used for a FTA New Starts application found that the bus speed model worked well and gave reasonable speeds as compared with actual run times. Such an improvement to the TPB model would return the need to loop back to the demographic submodels.

## 2.2 Changing HOV Skimming Method for HOT Facilities

Adjusting the skimming for the HOV and HOT facilities may provide an additional area of focus for reducing the model run time. The current Version 2.2 model framework requires two model runs to be performed for each feedback iteration to address HOV policy. The base model run captures the travel time for unimpeded flow of HOV traffic on HOT lanes consistent with the stated operational policy. The "conformity run" substitutes the HOV skims thus obtained for the HOV skims that would otherwise be obtained by simply skimming the networks with HOT lanes in operation. Streamlining this process has the potential to greatly decrease the run time of the model set.

An alternative methodology would be to skim the HOT facilities once for both HOT and HOV paths, with the tolls adjusted to achieve flow conditions consistent with the stated operational policy. For the HOV paths, the tolls would not be included in the path cost calculations. This change would provide HOV skims that would more accurately reflect traffic conditions on the arterial approaches to the HOT facilities, which could impact the HOV users' path choice. It could also serve to provide consistent link travel times for HOV and HOT paths.

CS recommends testing the impacts of making this proposed change in process before adopting it. For example, it would be important to determine if there is a change in the trip distribution that is unrelated to the issue of highway assignment convergence. It would also be beneficial to consider a way to dynamically determine the appropriate tolls to place on links to achieve flow conditions consistent with the stated operational policy for each iteration. For the test only, it may be useful to use a simpler assignment algorithm (rather than user equilibrium) to generate more-stable assignments which could be more-easily compared with one another for the impact of the change in HOV skimming technique. For example, an incremental capacity restraint approach or fixed percentages from the previous equilibrium assignment (essentially also an incremental capacity restraint approach) would lead to more stability in the output for this test. Following the test, the simpler assignment algorithm would not substitute for the validated highway assignment algorithm and process.

### 2.3 Removing the Transit Constraint

The current version of the model applies a core-capacity constraint to transit ridership destined for the region's core to reflect concerns surrounding the carrying capacity of the transit system. The transit constraint process caps transit ridership to the core at the Year 2010 level and transfers any overage to the single occupancy vehicle mode. Although the transit constraint does not significantly impact the run time for a particular loop of the model, it does impact the run time for the process as a whole since it requires a year 2010 model run be completed in order to be applied.

The transit constraint process is part of the air quality conformity modeling process and, therefore, is not easily removed without a solid justification. Indeed, it is present as a conservative gesture towards a concern about overstating the potential for transit ridership and to reflect the need for transit core-capacity improvements to be made to achieve the full ridership potential of the region. However, given the recent attention to making investments in Metrorail and regional bus to expand core-capacity it may be possible to revisit the application of the constraint from a policy point of view. It may also be possible to revisit the application of the constraint using an experimental point of view. That is, the impacts of removing the transit constraint on the final results could be evaluated and inform a discussion about the need to continue to apply it. Removing it would simplify the application and reduce the overall run time for testing scenarios with the model.

## ■ 3.0 Assignment Convergence

### 3.1 Background

One of the goals of implementing feedback loops is to incorporate the impacts of congestion on the other steps in the travel demand modeling process according to the theory that congested speeds and longer travel times impact where people travel and how they travel. The speeds and travel times that are part of the feedback process are skimmed from the loaded highway network. These skims are directly linked to the highway assignment algorithm and its performance. The convergence of the user equilibrium assignment with respect to travel times between all origin and destination pairs is key to getting relevant speed and travel time skims for the feedback process.

User equilibrium assignment is based on the Wardrop's condition that cost, mostly comprised of travel time, is equal along all paths used between all origin and destination pairs, such that no unused path between the pairs can be faster. Achieving this state is not simple in highly congested networks. The Frank-Wolfe path building algorithm is commonly applied to meet this condition. This algorithm is link-based and for each origin-destination pair it traces paths from all origins to the destination. It converges very well in small networks without high congestion. In large networks with high congestion levels it can require many assignment iterations to achieve convergence to a user equilibrium state.

The conventional standard for measuring convergence to a user equilibrium state is based on "relative gap," a measure of the difference between the current iteration and the perfect equilibrium assignment solution. Another measure, largely retired from use, "gap," is of the difference between the current iteration solution and that of the previous iteration.

Caliper Corporation presented a paper about the required conditions for user equilibrium and relative gap at the recent 2009 TRB Application Conference in Houston, Texas. Caliper showed that a network is at equilibrium and represents a stable solution when relative gap is less than or equal to $10^{-5}$. Dr. Michael Florian and Dr. Robert Dial have also stated that equilibrium with stability in the results is reached around the same threshold of relative gap.

The challenge with large congested networks has been achieving user equilibrium (i.e., meeting the threshold relative gap condition) using the Frank-Wolfe algorithm. It can take hundreds of iterations to reach this threshold in such networks, yet stopping the process before this state is reached produces a very unstable assignment result. (Unstable is used here to describe the condition where a small change in one area of the network results in a large number of unrelated changes in other parts of the network.) Research has shown that these unrelated changes which have been observed in applying user equilibrium assignment using the Frank-Wolfe path building algorithm are due to applying an insufficient number of iterations, i.e., short circuiting the application process. The end result is that comparison of alternatives using results from such a short-circuited process is quite difficult.

The run time to apply hundreds of iterations of the Frank-Wolfe algorithm to reach a stable user equilibrium state with a relative gap of $10^{-5}$ for congested networks similar to that in the Washington metropolitan area is currently not practical. Often, instead, the assignment model is stopped at a maximum number of iterations. However, with a capped number of iterations, the results are potentially unstable. Even though the final link volumes might closely match counts for a specific validation year, the issue of stability in assignment results cannot simply be overlooked. If a network improvement results in illogical changes in other parts of the network, communicating confidence in the results, sharing the results with decision-makers, and obtaining stakeholder buy-in can be a challenge.

The TPB Version 2.2 model applies a maximum of 60 iterations, triple the 20 iterations applied in Version 2.1D#50. However, a criterion for relative gap convergence is not used and stability of the assignment results appears to remain a concern. Changing the link capacity coded in the model on U.S. 29 in Montgomery County, for example, results in output showing a greater than 10 percent change in volume on I-95 in Fairfax County, a hard to explain result for an area far removed from the tested expansion. It is recommended that testing be done to calculate the relative gap measure with the current iteration cap and that additional iterations be considered to the extent that improved assignment stability might be achieved. Of course, added iterations will introduce added running time.

Given the problems with the Frank-Wolfe algorithm, in recent years there has been research into developing algorithms that reach convergence faster. These algorithms are based on the theory of saving acyclic subnetworks which leads to a more efficient shortest path calculation. The software vendors have shown that they are responding to the issues with convergence in the highway assignment and are developing improved algorithms for their software. Currently, INRO, PTV, and Caliper have developed these types of algorithms. INRO's algorithm was developed by Dr. Florian and is being built into EMME software. PTV is employing Dr. Dial's Algorithm B. Caliper also worked with Dr. Dial to develop a refined Origin User Equilibrium (OUE) algorithm for TransCAD and has incorporated it into the currently available Version 5.0 of the software. Citilabs is working on a refinement to the Frank-Wolfe algorithm that will allow for it to converge more quickly and also has stated that they are working on incorporating an acyclic subnetwork type of algorithm into their products in the near future. Currently, Dr. Boyce and Dr. Hillel Bar-Gera are researching the impact of these types of algorithms on route flows, whereas the to-date evaluation of these algorithms has focused on just the link flow results.

It is important to note that although the acyclic type of path building algorithms can reach convergence dramatically faster than the Frank-Wolfe algorithm, activities like performing a select link analysis are not possible using these methods. Dr. Boyce and Dr. Bar-Gera are researching how to get acyclic type of algorithms to work with select link analyses, but at this time there is no solution for this issue. However, solving this problem is important to permitting these methods to be used more widely in model application activities. Select link analysis is an important tool in model application for project planning and corridor studies. Among the applications are: determining impacts resulting from changes in land use inputs, performing Virginia Section 527 review analysis, reviewing toll facility usage for traffic and revenue studies, and calculating areas of project influence for impact fee assessment. Select link analysis is also important for performing subarea extractions, which can be used to determine the impacts of developments, allow for network improvement testing, and are a key input for traffic microsimulation studies.

According to TRB Special Report 288, over 75 percent of large MPOs employ a user equilibrium assignment process though only a few have models as large and as congested as TPB. Many of these organizations face the same issues as TPB in terms of convergence and run time.

The largest MPOs, New York, Los Angeles, and Chicago each take a slightly different approach to traffic assignment. Chicago uses the EMME/2 Capacity Constrained Equilibrium Highway Assignment module with a convergence criterion which looks at average zone-to-zone path times and average link travel times. If these are within at least one-half minute of one another, the highway assignment terminates. Otherwise, a 25 iteration cap is imposed (which typically occurs in the morning peak period assignment). Los Angeles Southern California Association of Governments (SCAG) uses a standard user equilibrium assignment in TransCAD. The model is set up for up to 10 feedback loops and a maximum of 40 iterations, with a relative gap target of 0.01. New York employs the TransCAD user equilibrium highway assignment method and does not achieve convergence due to the congestion on the network. The process employs 25 iterations for midday, evening peak, and off-peak periods, and 35 iterations for the morning peak period.

The Puget Sound Regional Council (PSRC) avoids employing a fixed iteration cap, but uses a relative gap criterion for convergence of 0.02, which requires fewer iterations to achieve than the recommended $10^{-5}$. Although this approach still results in instability in the final assigned volumes, given run time limitations it is practical and at least provides a criteria for convergence approach (which could be lowered over time as computer processing power improves) versus a maximum number of iterations.

The Baltimore Metropolitan Council (BMC) runs an equilibrium assignment for a base year, but takes the final fixed weights for each assignment iteration and uses those percentages in an incremental capacity restraint algorithm for model application. This approach addresses the issue of instability of assignment results, but it does not achieve user equilibrium.

## 3.2 Strategies

It is recommended to focus on ways to improve convergence of the assignment process while remaining conscious of the run time implications. To achieve this goal, CS recommends considering the following four strategies:

**Establish Convergence Criteria.** An adjustment in the assignment framework should be considered to use a convergence criterion to control the number of iterations rather than using a fixed number of iterations. It is recommended that a testing program be pursued to explore what impacts small changes in the network have with different convergence criteria. Ideally, the convergence criteria can be set directly based on these tests, but should run time remain the controlling constraint, perhaps setting the relative gap criteria threshold at $10^{-3}$ or $10^{-4}$ will produce more stable results than the current method.

**Enhance Computing Power.** Some agencies are looking towards taking advantage of advanced multiprocessor, distributed, and cluster computing options to speed up the highway assignment process and enable additional iterations. These include using computers with multiple processors, distributed processing to several computers, and cluster computing with several computers acting as one. High-end multiprocessor-equipped computers can facilitate processing speed. Several of the modeling software vendors support forms of distributed processing. For example, Cube Cluster can be used to distribute processing and improve run times as has been tested and demonstrated by TPB staff. There is a consideration to be made as to the ability of stakeholder agencies and entities to also obtain the required hardware and software to rely on this approach to model run time enhancement.

**Explore Alternative Algorithms.** As was discussed in the issues section, the possibility also exists to explore the application of alternative assignment algorithms to the Frank-Wolfe algorithm. The near-term availability of an improved algorithm from Citilabs would have the benefit of being able to use the existing software platform while achieving improved convergence (assuming the number of iterations is increased). In the absence of improved algorithms in the existing software platform, consideration could be given to migrating the model to an alternative platform with available faster assignment algorithms to permit achieving improved convergence. Any shift in algorithms, though, would need to consider the resulting availability of output to support decision-making, e.g., select link analysis.

**Introduce More Time Periods**. Since reaching convergence on a large congested network is the primary issue, another strategy could be to increase the number of time periods modeled. Currently, the model focuses on a morning peak period, an evening peak period, and an offpeak period. The model is not validated for these periods and they are developed using a set of static factors. Despite the limitations of the time-of-day factors (that they are static rather than from a choice type model) the current time-of-day application does add value to the assignment process. Adding additional time periods to the peak periods could help in reaching convergence by reducing the congestion on some links, in reality just making the trip tables smaller for each assignment. This approach would assist in reaching the convergence goal but would not directly improve model run time. However, with better convergence there may be the potential to reduce the number of feedback iterations as a whole. A negative aspect of this strategy is that it also may provide some confusion for users who even today use the peak-period assignments without understanding the limitations they imbed and that they are not individually validated.

## ■ 4.0 Feedback Convergence

### 4.1 Background

The goal of the feedback process is to account for the impacts of congestion on travel demand. A primary consideration in developing the feedback process is at what step should the output from a prior run plug into the next run (i.e., to what step should the feedback loop be connected). A second important consideration is how many iterations should be performed and what feedback convergence criteria should be used to end the process.

TRB Special Report 288 reported that over 80 percent of large MPOs feed network times back to the distribution and mode choice steps, while 40 percent of all MPOs feed congestion effects back to forecasts of land use and auto ownership. Most MPOs use a fixed number of feedback iterations which is usually not determined by any specific criteria.

The largest MPOs (New York, Los Angeles, and Chicago) use a fixed number of feedback loops, updating travel times and costs and restarting the model from an earlier stage (typically trip distribution) and running through highway and transit assignment. This fixed feedback loop approach does not include a convergence criterion that would shorten the number of feedback loops. Los Angeles and Chicago implement five global iterations and New York implements four.

Employing a heuristic which would determine when to end the feedback loop process is a recommended approach. However, the Denver Regional Council of Governments (DRCOG) is one of only a few MPOs with such a criterion for the number of feedback loops. The DRCOG feedback convergence criterion is based on achieving one percent or less of links with a greater than 10 percent change in link volume. Once this objective is achieved, the model terminates the feedback process.

The TPB Version 2.2 model has a total of six iterations following the "pump prime" run. The Version 2.1D#50 model also used six iterations, but the Version 2.1C model only used three. One reason for increasing the number of iterations was that the prior model exhibited issues with the end link volumes as compared to the final trip table resulting from the MSA approach for each iteration. This still can be an issue with results using the current Version 2.2 model. That is, there is still a disconnect between the results of the trip distribution and mode choice models as they relate to the final highway assignment, but the final trip table is now closer to the link flows.

## 4.2 Strategies

A few strategies for improving the feedback process are offered as recommendations, including: to review the possibility of reducing the number of feedback iterations through the establishment of convergence criteria, to consider an adjustment in the way in the final iteration is performed to enhance the usability of model output, and to consider employing a hybrid assignment approach within the feedback process:

**Reducing Feedback Iterations.** Few agencies have as many feedback iterations as TPB. The TPB staff should use a heuristic approach to determine the minimal number of feedback iterations required to achieve a set convergence goal. The specific criterion used by DRCOG may not be appropriate to use for the Washington metropolitan area due to the heavy congested and the potential that too many iterations would be required. One possibility, particularly due to the importance of air quality conformity to the region, is to focus the feedback criteria on the change in vehicle-miles of travel (VMT), e.g., when the change in VMT from one iteration to the next does not impact an air quality conformity determination. Another possibility is to use similar, but relaxed criteria as compared with

DRCOG, e.g., permit a larger percentage of links having changes greater than 10 percent in volume from one iteration to the next.

It is recommended that a heuristic approach be used to set the number of iterations for each horizon year. This could help to ensure stability in forecasts for project evaluation by imposing the same number of iterations across applications for a particular horizon year. The iteration count could be reevaluated from time to time.

**Reviewing MSA Application.** Many MPOs incorporate a MSA technique in the speed feedback process. The goal of using MSA is to have equilibrium speeds and corresponding travel times available to be fed back into the trip distribution and mode choice model so as to capture the effects of congestion on travel demand.

The MSA link averaging technique is especially popular. However, use of MSA can introduce disconnects between the final trip table and the final assignment and resulting loaded network. This has been seen as a possible consequence of using MSA with too few feedback iterations.

Another way of applying MSA is to average trip tables rather than link volumes and this could be explored as a way of addressing this issue with the model. Another approach to this issue is to continue to use MSA link averaging for speed feedback, but to assign a final trip table in the final iteration such that the final link volumes on the loaded network relate directly to that trip table. That is, in the final iteration, assign the final trip table without the MSA application. This approach would lead to a potentially more-useful final product while not adversely impacting the desired objectives of using MSA in the first place.

**Exploring Hybrid Assignment Approach.** It may be possible to obtain reasonable speed feedback for prior-to-final iterations and a shorter overall run time through the use of a hybrid assignment approach. Such an approach might employ an equilibrium assignment with strong convergence criteria at both the beginning and end of the feedback loop process, but in the middle iterations employ a different assignment method (such as an incremental assignment informed by the initial equilibrium assignment) or a lesser convergence criteria for equilibrium assignment. Such an approach would need to be tested for how it might affect model outputs, but could have merit as a way to achieve the multiple objectives of a robust speed feedback process, a converged final user equilibrium assignment, and reduced overall running time.

## 5.0 Recommendations

The current TPB Version 2.2 model and the upcoming Version 2.3 model require long periods of time to run. The goal of reducing the run time while maintaining or improving upon the current level of accuracy of the model is laudable. This memorandum has identified several possible areas of focus to improve run time. Recommendations, listed in approximate priority order, include the following:

- Apply the method of successive averaging (MSA) procedure for speed feedback but still assign a final trip table to the highway network. This will provide continuity in the final trip tables, the transit assignment applied in the Version 2.3 model, and the final loaded highway network regardless of the number of feedback iterations. It will also provide for continuity in application of select link and subarea extractions.

- Determine a criterion for the number of feedback loops. A level of confidence in the forecast can help guide the criteria. Given a level of confidence in the forecast, the feedback should be run until that level of change is seen in the trip distribution model. It is accepted as a state-of-the-practice technique for this procedure to use a heuristic approach. It will be important to document the process so it can be understood by decision-makers, stakeholders, and users of the model.

- Set criteria for relative gap convergence instead of a maximum number of iterations for the highway assignment in the short term.

- Consider investing in enhanced computing power to reduce overall run time of an improved model framework.

- Follow the developments in acyclic subnetwork path-based algorithms. In the near term, improvements to the algorithms should provide the ability to reduce the number of speed feedback iterations and provide for faster convergence in highway assignment.