November 2007 ■ RFF DP 07-43

DISCUSSION PAPER

Washington START Transportation Model

Description and Documentation

**Sébastien Houde, Elena Safirova,
and Winston Harrington**

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES
FOR THE FUTURE

Washington START Transportation Model: Description and Documentation

Sébastien Houde, Elena Safirova, and Winston Harrington

Abstract

The document describes the Washington START transportation simulation model. In particular, it provides information about the model structure, the equilibrium concept, and the data used to calibrate the model. It also briefly describes the reference scenario and the elasticity analysis. Finally, the document discusses past and potential future applications and possible directions for model extensions.

Key Words: transportation simulation, policy analysis, general equilibrium, travel demand, transportation network, mode of transportation

JEL Classification Numbers: R4, R41

Contents

Washington START Transportation Model: Description and Documentation

Sébastien Houde, Elena Safirova, and Winston Harrington[*]

1. Introduction

Washington START is a strategic transport model calibrated for the Washington, DC metropolitan area by researchers at Resources for the Future. The model represents the area's urban transportation network at the medium scale and can be used for transportation policy simulations at the metropolitan level.

The START modeling suite was developed by MVA Consultancy and has been applied to a range of urban centers in the United Kingdom, including Manchester, Birmingham, and Edinburgh (May et al. 1992, Croombe et al. 1997). The present version of the model has been calibrated for Washington, DC. Although most of the model components are conventional, the suite features a limited number of zones and an aggregated representation of the supply side combined with a very detailed demand side. An important advantage of the model is its relatively short run time, which provides an opportunity to conduct a large number of policy simulations.

During the period 2001–2006, the START model was calibrated for the Washington, DC region and underwent a series of improvements beyond the standard MVA package. In particular, an explicit distinction of single-occupancy vehicles (SOVs) and high-occupancy vehicles (HOVs) was introduced, and HOV lanes were incorporated into the network. Later on, modeling of the public transit was improved to (1) better represent combined rail networks; (2) allow cars and busses to share the same network; and (3) represent MetroRail park-and-ride facilities. Also, several utilities that facilitate policy evaluations using the model have been written. The most important is the welfare calculator, which computes changes in the travelers'

---

[*] Sébastien Houde is a Research Assistant, Elena Safirova is a Fellow, and Winston Harrington is a Senior Fellow at Resources for the Future. The calibration and improvements of Washington START benefited from the contributions of many persons, including Elena Safirova, Winston Harrington, David Mason, Peter Nelson, Kenneth Gillingham, Abram Lipman, Andrew Baglino, and Sébastien Houde. Address correspondence about this document to safirova@rff.org.

utility disaggregated by income class. This document describes the Washington START model in its 2007 version.

2. Model Overview

START is a simulation model designed to predict the transportation-related outcomes of different transportation policies. The model contains two submodels referred to as the supply side and the demand side. In this section, we present the level of disaggregation and the main features of the model. We also discuss how the model solves. Figure 1 presents a flow diagram of the Washington START that summarizes the level of disaggregation.

2.1. Overview: Supply Side

The supply side consists of the transportation network disaggregated into travel zones. Washington START has 40 travel zones such that county boundaries do not split travel zones into smaller parts, as shown in Figure 2. Each zone has three stylized transportation links (inbound, outbound, and circumferential) and a number of other “special” links that represent the principal freeway segments and bridges of the region (Figure 2). Note that HOV lanes are distinguished on the network. The traffic quality for each link is characterized by a monotonic equation. In each zone, parking is modeled explicitly.

In addition to car-related features, the supply side also incorporates public transit. In the present calibration of the model, the rail network of the region combines the Washington MetroRail system and suburban heavy rail systems: the Maryland Rail Commuter (MARC) and the Virginia Railway Express (VRE). Park-and-ride facilities for the MetroRail are also modeled. Bus travel is represented by a highly stylized route network. A special feature of the supply side is that transit crowding penalties are explicitly included in the model. The supply side computes the generalized costs of trips taking into account the time and monetary elements of traveling. Time elements include the time spent traveling, transit waiting time, parking search time, and transit crowding penalties. Monetary elements include car operating costs, car depreciation costs, parking fees, tolls, and transit fares. The value of time (VOT) is a function of the travelers’ wage rate and varies by trip purpose.

2.2. Overview: Demand Side

The demand side is a strategic model centered on nested logit models. In START, trip purposes and origins are taken as given. Travelers choose whether or not to generate a trip, destination, mode, time of day, and route. Nest order may be interchanged for different purposes.

The model distinguishes four motorized travel modes: SOV, HOV, transit (which has two submodes, bus and rail), and nonmotorized (walking and biking). It also represents three time periods: morning peak, afternoon peak, and off peak. Travelers maximize their utility of travel based on the generalized cost of travel, which combines time and money costs that are explicitly modeled in the supply module as well as idiosyncratic preferences. Eight types of travelers correspond to four income classes. Each income class is divided in two subgroups based on vehicle ownership. The idiosyncratic preferences, however, ensure a full heterogeneity among travelers.

2.3. Overview: Equilibrium

The model is static and the equilibrium values correspond to a given weekday on the transportation network of metropolitan Washington for the year 2000.

The convergence algorithm of START is an iterative one. The trips computed in the demand side are loaded onto the supply-side network. The supply side uses the loads to compute costs of travel, which are passed back to the demand module. This process iterates until the costs of travel converge to equilibrium values. The model is referred to as strategic because the equilibrium on the network corresponds to a Nash equilibrium; each traveler adopts a travel strategy that maximizes his or her utility, taking the travel strategies of others as given.

3. Model Description

3.1. Supply Side

Like other trip-assignment models, the supply side of Washington START characterizes the transportation network. For this model, the transportation network includes roads, public transit, parking and, in a more stylized fashion, walking and biking facilities. This section describes these features in detail.

3.1.1 Road Network

The START network consists of a number of zones and links covering the study area. START links are not defined in terms of nodes, but by directional corridors through each of the zones. As a result, each START directional link has a single, unique link number rather than being identified by the two node numbers it connects, as is the case in the usual highway-assignment model.

For Washington START, local roads and freeways are differentiated, but their modeling philosophy is the same. A relationship between speed and capacity (flow●distance curve) is associated with every link. Note that START uses speed/flow●distance curves as opposed to the more conventional speed/flow curves. The speed/flow●distance curve must have speed decrease as flow●distance increases for all ordinates on the curve.[1] When the START demand submodel forecasts the number of trips between origin/destination (OD) pairs and accumulates these onto specific routes, and therefore onto links, the flow●distance information allows the link speed to be determined. For all type of links, intersections and junctions are not modeled.

Arterial Roads

START arterial road infrastructure is modeled in a stylized fashion. The concept is of a road area in which a group of roads are combined together. Consequently, each zone has three area links defined in it representing the local arterial roads: inbound radial, outbound radial, and circumferential radial links. This definition of START links first requires the identification of a geographic regional center. The regional center is the focal point for trips within a given catchment area. For Washington START, the Washington Downtown Core acts as the regional center.

As we will see in Section 4, the speed/flow●distance curves for local roads do not have a specific functional form. The impact of local road building or other improvement measures in a given zone can be represented by careful adjustments to the area's capacity.

Freeways

In Washington START, several freeway segments and bridges are characterized as "special links." The six main corridors (I-270, I-95, and US-50 in Maryland and I-66, I-95, and US-267 in Northern Virginia) that connect the outer suburbs to the central region within the circular road I-495/I-95 known as the Beltway are represented. In addition, the Beltway itself and two freeway segments inside of the Beltway area, I-395 and I-295, are represented (see Figure 2). Finally, HOV lanes are also characterized as individual links parallel to the freeway segments that they belong to. Freeway segments with HOV lanes are then split into two links, one

---

[1] One of the advantages of the speed/flow●distance curves is that when the traffic experiences hypercongestion (e.g., the speed/flow curve bends backward), the speed/flow●distance curve is still upward sloping, which guarantees the existence of a unique solution in START computations.

representing conventional lanes and the other representing HOV lane(s). The capacity of the links, as a consequence, has been adjusted for the different periods of the day. Note that the model theoretically allows SOV travelers to use HOV, but by doing so travelers are subject to a high penalty. Table 1 lists the bridges and the HOV lanes represented in Washington START.

Unlike local roads, a specific functional form has been adopted (Van Aerde 1995) to characterize the speed/flow●distance curves of the special links. We discuss the calibration procedure in Section 4.

3.1.2. Public Transit

The public transit system as modeled in the current Washington START model is broken into two submodes: rail and bus. For both submodes, fares, crowding penalties, and detailed travel time including waiting, boarding, alighting, and in-vehicle time are explicitly represented. Travel times and costs associated with park-and-ride are also represented for rail.

Rail

The rail network combines the Washington MetroRail system and two suburban heavy rail systems, MARC and VRE (Figure 3). Rail travel occurs on routes that are modeled as a series of rail links in which each rail line in each zone is modeled as an individual link, complete with individual capacity and frequency characteristics. This disaggregated modeling is feasible because of the small number of MetroRail and commuter rail lines in the Washington, DC metro area. In addition to rail links, usage-weighted park-and-ride segments on the road network are added to all rail routes. Therefore, urban commuters, who generally do not drive to the rail station, face short to nonexistent park-and-ride segments, but suburban commuters travel along longer park-and-ride routes.

Bus

Bus routes are much less tractable than rail and therefore are defined to be routes on the existing road network for each OD pair. As is customary in transportation network modeling, a bus is considered to consume the equivalent of x “car units” of road space on the network; in our case, $x = 2$. For each time period, buses are assumed to travel the most frequently used car route from the origin to the destination. In this way, congestion on the road network also affects bus riders. It follows that benefits from reduced congestion can also accrue to bus users. Bus accessibility in any zone is determined by the density of stops, frequency of service, and reported bus travel times.

Wait Time and Crowding Penalties

A special feature of START is that it explicitly characterizes the disutility of wait time or crowding due to excessive demand for transit services.

Additional wait time due to excessive demand is modeled with a waiting penalty curve. The curve establishes a relationship between the degree of loading to the probability of having to wait for the next vehicle (bus or rail). The probability, determined from the curve, is divided by the frequency to give an additional wait time that is then added to the wait time for the first vehicle.

The crowding penalty corresponds to a psychological factor that captures the discomfort of crowded vehicles and congested platforms. The crowding curve incorporates four comfort levels: sitting comfortably, sitting crowded, standing comfortably, and standing uncomfortably. The penalty is characterized as a percentage increase in the perceived time of traveling by transit (Lam, Cheung, and Lam 1999). In START, the cost of traveling by transit thus includes “real time” and “perceived time” components. Similarly to the waiting penalty, the crowding penalty is determined by a curve that establishes the relationship between the degrees of loading to a crowding penalty.

3.1.3. Parking

Parking supply is separately modeled for the different parking areas. Car trips destined for the internal zones are allocated between the following five parking categories:

- long-term parking with potential private nonresidential spaces;
- long-term parking that must use public spaces;
- short-term parking with potential private nonresidential spaces;
- short-term parking that must use public spaces; and
- trips not requiring parking.

Parking fees vary by parking category. By assumption, parking fees apply systematically for public spaces and vary with duration. There is no fee for private parking spaces.

The parking model in START assumes that for each trip purpose travelers have a given probability to choose between short-stay and long-stay parking. The model further assumes that private spaces are favored over public spaces. These are therefore filled prior to any allocation to public parking capacity. Any excess demand from private parking is loaded into public parking.

Parking space availability (by time period) is calculated based on average parking duration for long- and short-stay demand, respectively. Search time for a public parking space is related to levels of "parking lot" occupancy. A search-time curve relates aggregate parking lot occupancy to time spent searching for a space. This search time is added to the generalized cost of travel, and parking search mileage is added to highway vehicle flows. START assumes that on-road parking search speed is lower than normal traffic speed. Egress walk time from car to ultimate destinations is also related to public parking lot occupancy by means of an appropriate curve. As occupancy levels rise, START assumes that walk times become progressively longer. For private parking a single, a fixed value per parking area for egress walk time is used.

Park-and-ride parking facilities are characterized similarly. Fees, search, and egress costs are added to the generalized costs of rail trips.

3.1.4. Walking/Biking

In START, travelers can choose to travel by nonmotorized mode (walking or biking). Walking and biking infrastructure is not represented in START, and there is no interaction on the road network between the nonmotorized mode and other modes. For example, in Washington START bikers cannot slow cars on arterial roads. This mode is not congestible and it cannot be affected by changes in crowding levels in the transport infrastructure. Walking/biking trips are simply associated with a fixed duration, which is set to 10 minutes in Washington START.

3.2. Demand Side

The demand component of START aims to predict how travel will change as generalized cost changes. Travelers' transport choices (frequency of travel, destination, mode, time of day, and route) are explicitly represented.

In Washington START, there are eight types of traveler. Travelers are first split in four income groups, and afterward dichotomized by vehicle ownership. For the lowest quartile group, we differentiate between travelers not owning a vehicle or owning one or more. For the other quartiles, we differentiate between individuals who do not own a vehicle or own only one and individuals who own more than one vehicle.

There are six trip purposes: home-based work (HBW), home-based shopping (HBS), home-based other (HBO), non–home-based work (NHBW), non–home-based other (NHBO), and freight. Home-based trips either originate or terminate at home. START takes HBW trip and freight trip demands by each agent type and residential location as exogenous. Non–home-based trip demands are an explicit function of home-based trip numbers at the model level.

The model distinguishes four travel modes: SOV, HOV, transit (bus and rail), and nonmotorized (walking or biking). START also represents three time periods: morning peak, afternoon peak, and off peak. For a given OD pair, routes can be substituted. However, the number of available routes is predetermined.

3.2.1. Travelers' Decision Making

In START, a nested multinomial logit model is used to characterize travelers' decision making. The choices are organized into a hierarchy according to which the most sensitive choices are dealt with first, at the bottom of the structure, and the least sensitive choices are placed at the top of the structure. For home-based trip purposes, agents choose in successive nests whether or not to generate a trip, then destination, mode, time of day, and route.[2] The utility functions at each nest are linear in generalized costs (the combined monetary and time costs of travel). VOT is a function of the travelers' wage rate, and varies by trip purpose. The utility for each nest i given by

$$U_i = A_i - \beta p_i \tag{1}$$

where A_i is a calibrated value representing idiosyncratic preferences, β is an exogenous response parameter (indexed by trip purpose and nest level), and p_i is a generalized cost of travel that combines time and money costs explicitly modeled in the supply module. The following sections further describe the cost calculations for the different motorized modes.

Car Trip Cost Calculation

For car users, the generalized cost of travel is computed as follows:

$$p = v^* t + 2v^*(s + e) + d + l + k \tag{2}$$

---

[2] For shopping trips, the mode nest is above the destination nest.

where:

v^* : denotes VOT, set at 40 percent of the wage rate for all purposes except non-HBW trips, for which it is assumed that the traveler is "on the clock," and the VOT is therefore set at the wage rate. For waiting time, parking egress time, and parking search time, the VOT is doubled, since time spent in these activities is considered more unpleasant than time spent in-vehicle.

t : denotes the travel time

s : denotes the time required to find a parking space and is a function of the fullness of the parking area and one's parking category (reserved versus unreserved space), as well as of the physical characteristics of the parking area, such as lot size.

e : denotes the egress parking time.

d : denotes the monetary driving costs.

l : denotes the tolls paid, if present.

k : denotes the parking fee associated with the route.

Rather than working with absolute costs, the Washington START model uses cost differentials between the calibrated baseline and simulated policy scenarios to determine the costs that drive the logit model. For this reason, some costs do not need to be included in the formulas above. For example, time needed to walk from residential parking to the car is not included because this time is assumed to be the same in the baseline and policy scenarios.

Monetary driving costs include costs of fuel, fuel tax, vehicle depreciation, wear and tear, maintenance and parts, and insurance. In Washington START, a curve establishes a relation between speed and these driving costs.

Transit Trip Cost Calculation

Transit users face monetary costs as follows:

Bus:
$$p = f + 2v^*(1+2\pi)w + v^*(1+\rho)t \tag{3}$$

Rail:
$$p = f + 2v^* w + v^*(1+\rho)t + d^{pnr} + k^{pnr} + v^* t^{pnr} + 2v^*(s^{pnr} + e^{pnr}) \tag{4}$$

where:

v^* : denotes VOT (see above for details).

π : denotes the probability of missing a bus and having to wait for the next one (this constant also helps address the bunching effect often seen on bus routes) and is a function of the fullness of the bus.

w : denotes wait time.

ρ : denotes an increase in perceived time resulting from the crowding penalty. This perceived crowding penalty is purely psychological; it does not represent any real factor contributing to trip time.

t : denotes the travel time, including transfers between bus or rail lines.

The following variables pertain to the park-and-ride leg of rail routes. The park-and-ride leg is weighted to accurately represent the tendency of rail users to drive to and park at the origin rail station.

t^{pnr} : denotes the time required to drive from home to the rail station.

s^{pnr} : denotes the time required to find a parking space in a park-and-ride area.

e^{pnr} : denotes the time required to go from one's car to the rail station entrance.

d^{pnr} : denotes the monetary driving costs for the drive from home to the rail station.

k^{pnr} : denotes the parking fee associated with the route.

Again, the costs are expressed in relative terms between the calibrated baseline and simulated policy scenarios. Therefore, the time composites that remain unchanged are not included. For example, the time needed to walk to a bus stop is not included in the bus cost formula.

3.3. Equilibrium Algorithm

The algorithm that determines the equilibrium between the supply and demand sides in START uses an iterative process to find an equilibrium value for an array of costs. This array of costs, which includes all observable time and money costs incorporated into the model, serves as the convergence vector.

In the demand model, convergence vector costs are combined to compute the generalized cost for every node of the nested multinomial logit decision tree. Each traveler has a vector of costs consistent with his or her travel strategy, which is the one that maximizes his or her utility, taking the strategies of the other travelers as given. Once the travel strategies are determined for all travelers, the trips are assigned to the supply side in order to compute endogenous network characteristics such as congestion, link-by-link road speeds, and transit crowding. These values, in turn, are used to compute convergence vector costs. The costs are passed back to the demand model, and a new iteration begins. The process continues until the convergence vector costs converge to within a tolerance set by the user.

3. Data

The START modeling suite comes with a number of default parameters provided by the MVA consultancy. This section presents an overview of the default parameters and describes the sources of data specific to Washington START and how the data are used to construct the model.

4.1 Supply Side

The supply side is calibrated with default parameters provided by MVA and data specific to Washington, DC. The default parameters are primarily used for the characterization of the parking component (Table 2).

On the other hand, the road network and the morphology of the transit services and fares have been rigorously calibrated to approximate the metropolitan Washington transportation network.

Speed Flow●Distance Curves

An important element of the modeling of the road network is the characterization of the speed flow●distance curves. The speed flow●distance curves for the arterial routes of the network are characterized using data from the transportation model of the Metropolitan Washington Council of Government (MWCOG). This highly disaggregated model establishes the relationship between capacity (flow●distance) and speed for the arterial roads of metropolitan Washington at different periods of the day. MWCOG data have been aggregated to represent inbound, outbound, and circumferential links in a way consistent with the time periods and the zone delimitation adopted in Washington START.

The speed flow●distance curves for the special links (freeways and HOV lanes) have been characterized with the Van Aerde speed/density model, which is a single-regime model that simulates traffic for all ranges of speeds by the same equation:

$$D = \frac{1}{\left(c1 + \frac{c2}{(Sf - S)} + c3 \cdot S\right)} \tag{5}$$

where D is Density (vehicles/lane/mile); Sf is free-flow speed (mph), calibrated; $c1, c2, c3$ are Coefficients calibrated; and S is speed. Washington START's speed flow●distance curves based on the Van Aerde model (Van Aerde 1995) have been calibrated with SkyComp data (SkyComp1996, 2002) and MWCOG data. SkyComp (2002) provided the estimation of the model parameters for metropolitan Washington based on 1995 data. The coefficients $c1, c2, c3$ estimated are, respectively, 0.00512, 0.0144, and 0.000342, with a free-flow speed of 67 mph. Figure 4 shows the curve that results from this parameterization. Note that each density corresponds to a given level of service (LOS), where LOS E, as proposed by the Highway Capacity Manual 2000, corresponds to the maximum capacity of the route.

To make the Van Aerde model based on SkyComp data consistent with Washington START, the main challenge was to ensure the correspondence between density measures used by the Van Aerde model and the flow●distance measures used in START. To do so, the flow●distance observed on each special link (provided by MWCOG) has been associated with its corresponding LOS as observed by SkyComp (2002). Afterward, taking the shape of the curve as given, it has been possible to determine the flow●distance corresponding to the other LOS.

Routes

The MWCOG model is used to provide a set of predetermined routes between each OD pair. These routes are taken as given in Washington START. They vary from one to nine, but almost half of the OD pairs have the maximum numbers of routes (Figure 5).

Transit Service

Transit service frequency is calibrated by using the National Transportation Database, Washington Metropolitan Area Transit Authority (WMATA) 2002 Survey and budget documents [3] and reported data for the VRE and MARC commuter rail services.

Fares and Park-and-Ride

Transit fares are based on WMATA fares in 2000 and published VRE and MARC fares. For 2000, WMATA estimates the average bus fare at 60 cents versus $1.50 for rail. The probability of parking for park-and-ride is obtained from the WMATA 2002 Survey.

---

[3] See Federal Transit Administration (2000), Washington Metropolitan Area Transit Authority (2002) and Metro Funding Panel (2005)

Transit Services Morphology, Frequency, and Capacity

The bus and MetroRail morphology and frequency are obtained from WMATA. Similar data for heavy rail are obtained from VRE and MARC.

Transit Capacity

The bus and rail capacity are deducted from ridership data. The capacity is assumed to meet the base demand among the most-used transit routes. Ridership data are obtained from the WMATA 2002 Survey.

Transit Crowding Curve

The same crowding formula applies to bus and rail trips. The crowding formula is applied in a time-windowed approach, using WMATA data on demand characteristics broken down into half-hour intervals over each time period. This method ensures that the crowding calculation fully captures the peak of the morning and afternoon rush hour periods. Taking into account peaking attributes is important: there are 2.7 times as many peak rail trips as off-peak trips. For bus trips, the ratio is 2.4 (FTA 2000).

4.2 Demand Side

The majority of the data used to calibrate the demand side are specific to metropolitan Washington. However, the demand response parameters of the nested multinomial logit decision are taken from the MVA consultancy. Table 3 lists the response parameters used for each purpose.

Monetary Costs of Driving

Monetary costs of driving, including fuel, fuel tax, vehicle depreciation, wear and tear, maintenance, and insurance, have been obtained from the Highway Capacity Manual 2000. They are converted in 1990 dollars. These costs are used to construct curves that establish the relationship between speed and costs of driving. To do so, the costs are first classified in three categories: fuel including taxes, running but nonfuel costs, and fixed costs. Afterward, a curve is fitted for each of these categories with the following fourth-order polynomial:

$$d_i = \gamma_1 + \gamma_2 s + \gamma_3 s^2 + \gamma_4 s^3 + \gamma_5 s^4 \tag{6}$$

where d_i is monetary costs of driving for the cost of type i, with $i = 3$, s_i is speeds in mph, and γ is curve's coefficients.

START also considers a fourth type of costs, the perceived costs of travel, which are computed as the sum of the three types of costs. Table 4 presents the curve's coefficient for the four types of costs.

Trip Numbers

Trip numbers are necessary to reproduce the reference case. Their sources vary depending on the trip purpose considered in Washington START. The sources for each purpose are as follows:

- HBW trips (demand): Data from CTPP, Census 2000, AHS, CPS, and NHTS.
- HBS trips: WMATA Survey for Metro and 1994 Household Travel Survey
- HBO trips: WMATA Survey for Metro and 1994 Household Travel Survey
- non-HBW trips: WMATA Survey for Metro and 1994 Household Travel Survey
- non-HBO trips: WMATA Survey for Metro and 1994 Household Travel Survey
- freight trips: NHTSA freight trip generation methodology, CENSUS and CTPP

Value of Time and Wages

In Washington START, VOT is assumed to be 40 percent of the hourly wage rate. For each income group, the average hourly wage rate is determined from the Census and Bureau of Labor Statistics. Table 5 presents the wage rates and the associated VOTs used in START.

4. Reference Scenario

This section presents the reference scenario of Washington START. It characterizes the transportation network for the year 2000 under the assumption of business-as-usual.

Table 6 presents the generalized cost of travel for car and transit trips. All time and cost components are reported in costs per mile. Table 7 presents the average time of travel and monetary costs per trip. Note that Tables 6 and 7 report the average cost and time over all trips. There are, however, substantial variations. Tables 8 and 9 present the distribution of trips across modes, time periods, and car-ownership groups.

5.1. Elasticities

Unlike in partial equilibrium models, in general equilibrium models such as START elasticities are endogenous and are determined by both the exogenous response parameters and baseline levels of prices and distribution of trips. However, the model elasticities can be computed. Since these elasticities are obtained from model runs, they reflect not only the direct effect of an increase in a given variable, but also the secondary effects related to traffic congestion. Table 10 presents a selection of model elasticities that are compared with elasticities in the literature.

6. Policies

This section describes the range of policy simulations that have been done or can potentially be modeled with Washington START and discusses some extensions of the model.

6.1. Past Applications

Washington START has been used to conduct policy simulations of gasoline taxes (Nelson et al. 2003), HOT lanes (Safirova et al. 2003), and congestion pricing (Safirova et al. 2004; Safirova et al. 2005) as well as to compute network-based marginal congestion costs of urban transportation (Safirova, Gillingham and Houde 2007) and to evaluate the benefits of public transit (Nelson et al. 2007).

6.2. Potential Applications

The relatively short run time of Washington START[4] coupled with its richness of behavioral details allow a broad set of policy simulations, which can be classified in three categories.

First, there are policies related to the capacity of the network. New roads or simply changes in the existing capacity of the freeways or arterial roads can easily be simulated. Similar exercises can also be done with the transit network. For example, the metro rail network could be extended or the frequency of the bus services could be augmented to simulate investment in transit capacity.

Second, a number of pricing policies can be considered, where pricing policies refer to price instruments applied at different levels. For example, transit, parking fees, congestion taxes,

---

[4] *~20 minutes on a 2.6 GHz, 1.5G of RAM*

gas tax, or insurance premiums can all be modeled, independently or simultaneously, in Washington START.

Third, there is what we call optimum analysis, where not only a given policy is simulated, but its optimum level of provision is determined as well. Note, however, that Washington START is too complex to allow the computation of first–best transportation policy. However, a vast range of constrained optima and second-best policies can be determined, such as optimal gas tax, optimal metro fare, and optimal distance-based toll.

6.3. Extensions

On the methodological side, there are also promising extensions of Washington START. Safirova and colleagues (2006a,b) have integrated START with the regional economy and land use (RELU) model, a spatially disaggregated computable general equilibrium model of economic activity in the Washington, DC metropolitan area. The integrated model of land use, strategic transport, and regional economy (LUSTRE) provides a sound framework to study the interactions between transportation, land use, and economic activity.

Mobile emissions and urban air quality can also be modeled with Washington START. In a first step, the model can be coupled with the Environmental Protection Agency’s model MOBILE6.2 to produce emission scenarios. In a subsequent step, an urban airshed model can be linked to the emission model and used to simulate the urban air quality in the region.

Another promising avenue for the extension of Washington START is to consider a dynamic framework. Note that the development of this framework is closely linked to the integration of START with a land-use and economic model.

References

American Housing Survey (AHS) for the United States 2001: U.S. Census Bureau http://www.census.gov/hhes/www/housing/ahs/nationaldata.html.

Census Transportation Planning Package (CTTP) 2000: U.S. Department of Transportation http://www.fhwa.dot.gov/ctpp.

Consumer Expenditure Survey (CE) 2000: U.S. Department of Labor, Bureau of Labor Statistics http://www.bls.gov/cex.

Croombe, D. P., Scholefield, G. and Skinner, A. 1997. Study of Parking and Traffic Demand Part 3: The effects of parking control strategies in Bristol. *Traffic Engineering and Control* 38(2), February.

Current Population Survey (CPS): U.S. Census Bureau. http://www.census.gov/cps.

Federal Transit Administration National Transit Database 2000: http://www.ntdprogram.com/ntdprogram.

Highway Capacity Manual 2000. Transportation Research Board, Washington, 2000

Lam, H. K. William, Chung-Yu Cheung, and C. F. Lam. 1999. A study of crowding effects at the Hong Kong light rail transit stations. *Transportation Research Part A: Policy and Practice* 33:401-415.

May, A. D., Roberts, M. and Mason, P. 1992. The Development of Transport Strategies for Edinburgh. *Proceedings of the Institution of Civil Engineers: Transportation* 95, 51-59

Metro Funding Panel. Report of the Metro Funding Panel. Washington, DC 2005: http://www.mwcog.org/uploads/committee-documents/pVxfXFs20050106084602.pdf

Metropolitan Washington Council of Government. MWCOG Transportation Model http://www.mwcog.org/transportation/activities/models.

National Household Travel Survey (NHTS) 2001: U.S. Department of Transportation http://nhts.ornl.gov/2001/index.shtml.

Nelson, P., Gillingham, K., Safirova, E., 2003. "Revving up the Tax Engine: Gas Taxes and the DC Metro Area's Transportation Dilemma," RFF Issue Brief 03-05.

Safirova, E., Gillingham, K., Harrington, W., Nelson, P. 2003. "Are HOT Lanes a Hot Deal? The Potential Consequences of Converting HOV to HOT Lanes in Northern Virginia," RFF Issue Brief 03-03.

National Capital Region Transportation Planning Board. 2003 Update to the Financially Constrained Long-Range Transportation Plan for the National Capital Region. Washington, DC http://www.mwcog.org/uploads/pub-documents/+FxdXQ20041119144517.pdf.

Nelson, P., A. Baglino, W. Harrington, E. Safirova, and D.A. Lipman. 2007. Transit in Washington DC: Current Benefits and Optimal Level of Provision. Journal of Urban Economics, forthcoming

Safirova, E., W. Harrington, P. Nelson, I.W. Parry, K. Gillingham, and D. Mason. 2004. Welfare and Distributional Effects of Road Pricing Schemes for Metropolitan Washington, DC. In *Road Pricing: Theory and Evidence*, edited by G. Santos. New York: Elsevier, pp. 179-206

Safirova, E., K. Gillingham, W. Harrington, P. Nelson, and D. Lipman. 2005. Choosing Congestion Pricing Policy: Cordon Tolls vs. Link-Based Tolls. *Transportation Research Record* 1932: 169-177.

Safirova, E., K. Gillingham, and S. Houde. 2007. Measuring Marginal Congestion Costs of Urban Transportation: Do Networks Matter? *Transportation Research Part A.* Forthcoming.

Safirova, E., S. Houde, D. Lipman, W. Harrington, and A. Baglino. 2006. Congestion Pricing: Long-Term Economic and Land Use Effects. Discussion paper 06-37. Washington, DC: Resources for the Future.

SkyComp Inc. Traffic Quality on the Metropolitan Washington Area Freeway System Final Reports 2002 & 1996: Prepared for the National Capital Region Transportation Planning Board /Metropolitan Washington Council of Governments http://www.mwcog.org/uploads/pub-documents/+VteXg20050429150358.pdf.

U.S. Census Bureau. Census 2000. http://www.census.gov/main/www/cen2000.html.

U.S. Department of Transportation. National Highway Traffic Safety Administration (NHTSA) http://www.nhtsa.dot.gov.

Van Aerde, M. 1995. Single Regime Speed-Flow-Density Relationship for Congested and Uncongested Highways. Paper presented at the 74th Transportation Research Board (TRB) Annual Conference. January 1995, Washington, DC.

Washington Metropolitan Area Transit Authority (WMATA): Passenger Survey Final Report 2002; Fiscal Year 2000 Budget.

Tables and Figures

Table 1. Bridges and HOV Lanes Represented in Washington START

Bridges
American Legion Bridge
Memorial Bridge
Theodore Roosevelt Bridge
14th Street Bridge
Woodrow Wilson Bridge

HOV Lanes
I-95 HOV
I-395 HOV
VA 267 HOV
I-270 HOV

Table 2. Exogenous Parameters Provided by MVA Consultancy

START Variable Name	Description	Disaggregated by	Units
LPAREA	Parking area associated with link	link	
PARTEN	Probability of parking	purpose, parking type (short stay and long stay)	
PNHB	Propensity to make non–home-based trips	home-based purpose	
TELDPK	Loading coordinates for parking load/egress time curves (for each public parking area/type, given as a set of ordered pairs of the form [proportion full, egress time])	-	
TEPRKA	Fixed egress time for private parking	parking area, parking type (short/long)	Minutes
TSLDPK	Loading coordinates for parking load/search time curves (for each public parking area/type, given as a set of ordered pairs of the form [proportion full, search time])	-	
UPARK	Parking capacity	parking area, parking type (short/long), parking hierarchy (private/public)	Parking spaces
BCLD	Loading coordinates for probability of waiting for the next vehicle (curves are given as a set of ordered pairs of the form [loading proportion, waiting probability])	bus, rail	
BCPTY	Waiting probability coordinates for probability of waiting for the next vehicle (curves are given as a set of ordered pairs of the form [loading proportion, waiting probability])	bus, rail	Minutes
PSPEED	Speed of cars on the road that are looking for parking spots	-	Miles/Minutes
TEPK	Egress time coordinates for parking load/egress time curves (for each public parking area/type, given as a set of ordered pairs of the form [proportion full, egress time])	-	Minutes
TSPK	Search time coordinates for parking load/egress time curves (for each public parking area/type, given as a set of ordered pairs of the form [proportion full, search time])	-	Minutes

Table 3. Demand Response Parameters: Nested Logit

	Home-based work (min[a])	Home-based shopping (min)	Home-based other (min)	Non–home-based work (min)	Non–home-based other (min)
Trip generation	–0.0045	–0.005	–0.0045	–0.0045	–0.0045
Destination choice	–0.02	–0.05	–0.02	–0.02	–0.02
Mode choice	–0.05	–0.05	–0.05	–0.05	–0.05
Time choice	–0.05	–0.1	–0.09	–0.1	–0.1
Route choice	–0.185	–0.185	–0.185	–0.185	–0.185

[a] In Washington START the generalized cost of travel are computed in minutes, and the response parameters are in the same units.

Table 4. Coefficients in the Monetary Costs of Driving Equation

	γ_1 (in 1990$)	γ_2 (in 1990$)	γ_3 (in 1990$)	γ_4 (in 1990$)	γ_5 (in 1990$)
Fuel Costs	8.763	–0.391	0.0112	–0.000138	0.000000743
Running Nonfuel Costs	5.691	–0.122	0.00548	–0.0000789	0.000000478
Fixed Costs	29.007	–1.060	0.0291	–0.000391	0.00000196
Perceived Costs	43.461	–1.573	0.0458	–0.000608	0.00000318

Table 5. Wage Rates and Corresponding Values of Time (VOT)

	Wage Rate ($/h in 1990$)	VOT ($/h in 1990$)
Skill Level 1	8.52	3.41
Skill Level 2	17.81	7.12
Skill Level 3	28.43	11.37
Skill Level 4	59.34	23.74

Table 6. Generalized Cost of Travel Baseline Calibration

Generalized Cost of Travel of Car Trips

Time Components	**Average Cost per Mile (1990 cents)**
Time of Travel Excluding Parking Time	20.89
Parking Time	0.70
Total	21.59

Cost Components	**Average Cost per Mile (1990 cents)**
Fuel Tax	1.24
Parking Fees (Average)	0.62
Fuel Cost (net of taxes)	2.96
Operating Costs (nonfuel): Tires, Maintenance, Oil	6.06
Depreciation	9.48
Insurance	3.13
Total	23.49
Generalized Cost of Travel of Car Trips: All Cost Components (Time and Monetary)	**45.08**

Generalized Cost of Travel of Transit Trips

Time Components	**Average Cost per Mile (1990 cents)**
Travel Time (Excluding Crowding Effects)	25.95
Crowding Time	6.49
Waiting Time	11.57
Park-and-Ride Time (Excluding Parking Time)	2.22
Parking Time Park-and-Ride	0.65
Total	46.88

Cost Components	**Average Cost per Mile (1990 cents)**
Fares	8.55
Park-and-Ride Parking Costs (when applicable)	17.14
Total	25.68
Generalized Cost of Travel of Transit Trips: All Cost Components (Time and Monetary) Except Parking Costs	**55.42**

Table 7. Trip and Trip Cost Values for Baseline Calibration

	Average Travel Times per Trip (min)	Average Monetary Costs per Trip (in 1990$)	Trips per Day (,000)	Share (%)
SOV	18.47	2.73	11707	47.49
HOV	16.89	2.33	10093	40.94
Bus	30.12	0.47	515	2.09
Rail	30.29	1.24	646	2.62
Walk/Bike	10	-	1690	6.85

Table 8. Trips Split by Time Period and Mode

	Trips per Day (,000) Morning Peak	Share (%)	Trips per Day (,000) Evening Peak	Share (%)	Trips per Day (,000) Off Peak	Share (%)
SOV	2316	50.91	3632	45.77	5758	47.34
HOV	1699	37.34	3476	43.80	4918	40.42
Bus	97	2.13	143	1.80	275	2.26
Rail	188	4.12	224	2.82	235	1.93
Walk/Bike	250	5.50	461	5.81	978	8.04

Table 9. Trips Split by Car-Ownership Group and Mode

		Trips per Day (,000)					Mode Share (%)				
Income Groups	Car Ownership	SOV	HOV	Bus	Rail	Walk/ Bike	SOV	HOV	Bus	Rail	Walk/ Bike
Quartile 1	0	1848	1254	103	81	228	52.6[5]	35.7	2.9	2.3	6.5
	>0	1694	1269	48	49	221	51.6	38.7	1.5	1.5	6.7
Quartile 2	0–1	558	946	95	62	91	31.9	54.0	5.4	3.6	5.2
	>1	1992	1308	49	80	204	54.8	36.0	1.3	2.2	5.6
Quartile 3	0–1	546	796	63	78	151	33.4	48.7	3.9	4.7	9.3
	>1	3569	3210	95	173	506	47.2	42.5	1.3	2.3	6.7
Quartile 4	0–1	130	147	16	17	73	33.9	38.5	4.1	4.5	19.0
	>1	1370	1162	46	106	216	47.2	40.1	1.6	3.7	7.4

---

[5] It might appear counterintuitive to see a high proportion of trips made by SOV for travelers identified as having no cars and low income. However, these travelers probably live in households where they have access to a car, but do not own it. Students are probably the best example of travelers fitting this category.

Table 10. Elasticities Computed in Washington START

Elasticity	Washington START	Compare To:
PT Trips WRT Fuel Price	0.088	0.07 (Luk and Hepburn 1993)
Bus Trips WRT Bus Fare	–0.291	–0.28 short run, –.55 long run (Goodwin 1992)
Train Trips WRT Train Fare	–0.732	–0.65 short run, –1.08 long run (Goodwin 1992)
VMT WRT Fuel Price	–0.169	–0.16 (de Jong and Gunn 2001) –0.1 (Goodwin et al. 2003)

Figure 1. Flow Diagram of Washington START

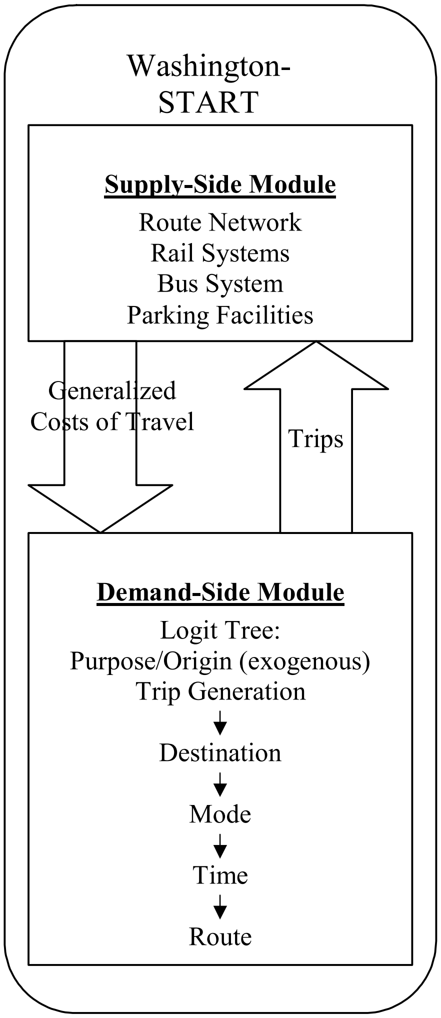

Figure 2. Washington START Modeling Region with All Special Links

Zone Number	Description
1	DC Downtown
2	DC Northwest
3	DC Northeast
4	DC Southeast
5	Montgomery Co. Southwest
6	Montgomery Co. Southeast
7	Montgomery Co. West
8	Montgomery Co. East
9	Montgomery Co. Northeast
10	Prince George Co. Northwest
11	Prince George Co. Southwest
12	Prince George Co. Northeast
13	Prince George Co. Southeast
14	Frederick Co.
15	Carroll Co.
16	Howard Co.
17	Anne Arundel Co.
18	Calvert Co.
19	Charles Co.
20	Arlington East
21	Arlington South
22	Arlington West
23	Alexandria
24	Fairfax Co. East
25	Fairfax Co. Northeast
26	Fairfax Co. South
27	Fairfax Co. Northwest
28	Loudon Co. East
29	Loudon Co. West
30	Prince William Co. South
31	Prince William Co. North
32	Stafford/Fredericksburg Co. North
33	Fauquier Co.
34	Clarke Co.
35	Stafford/Fredericksburg Co. South
36	King George Co.
37	External Zone, South
38	External Zone Southwest
39	External Zone, Northwest
40	External Zone, East

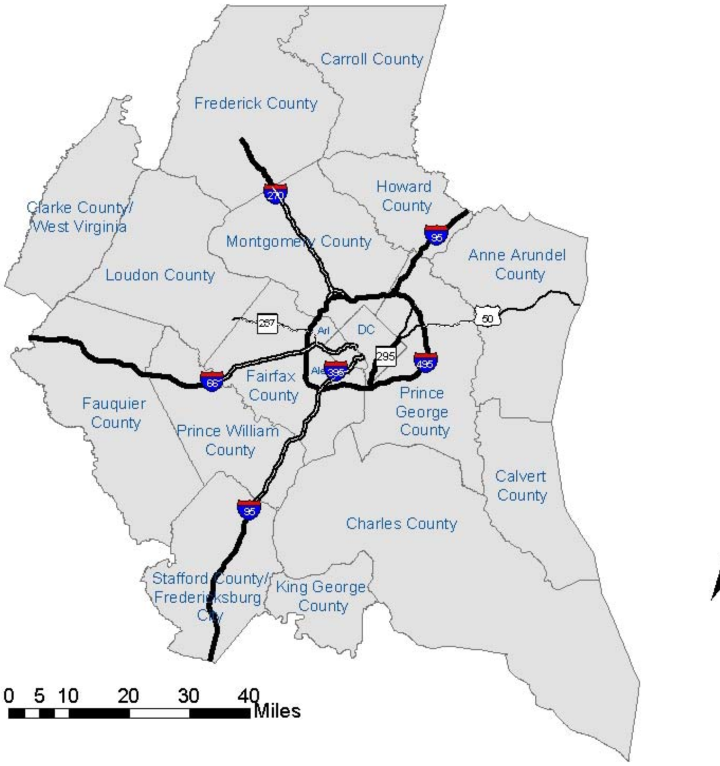

Figure 3. Commuter Rail (left) and MetroRail (right)

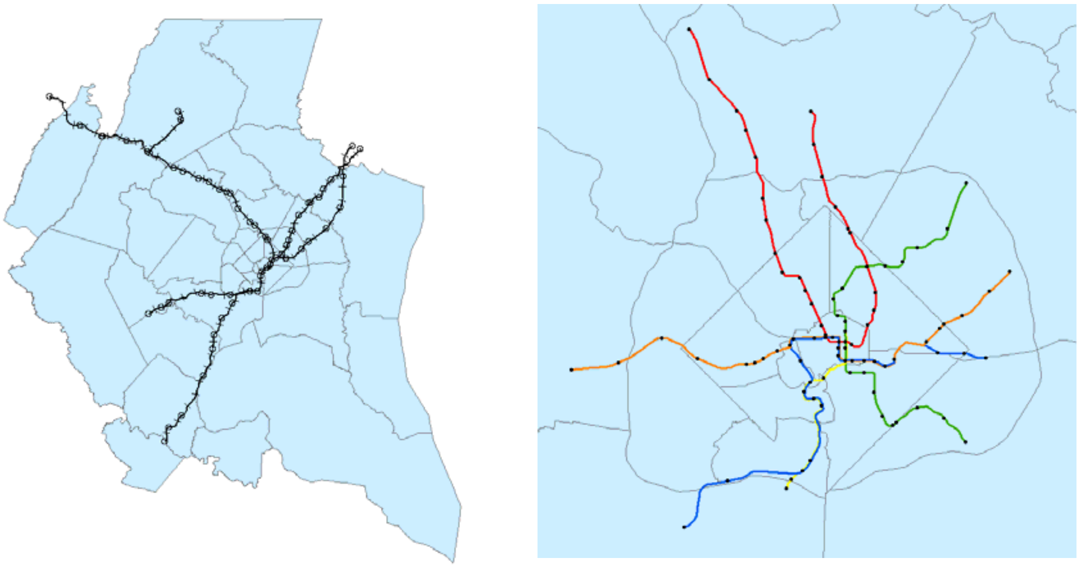

Figure 4. Density/Speed Relationship

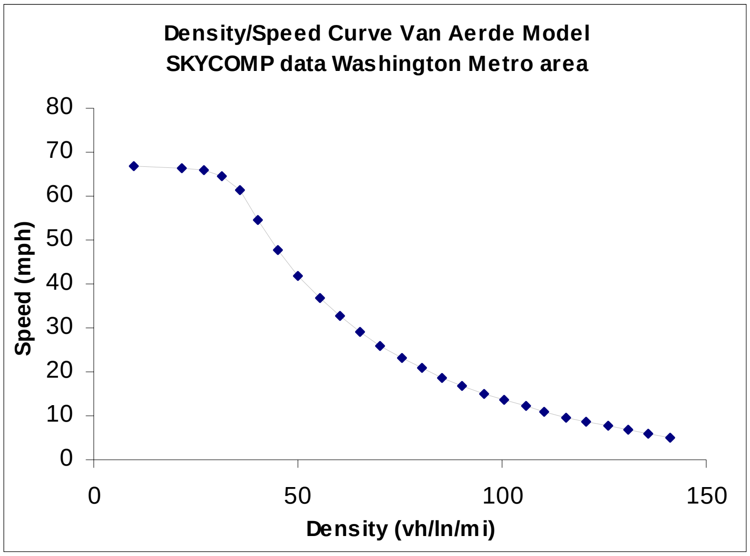

Figure 5. Distribution of Origin–Destination (OD) Pairs by the Number of Connecting Routes

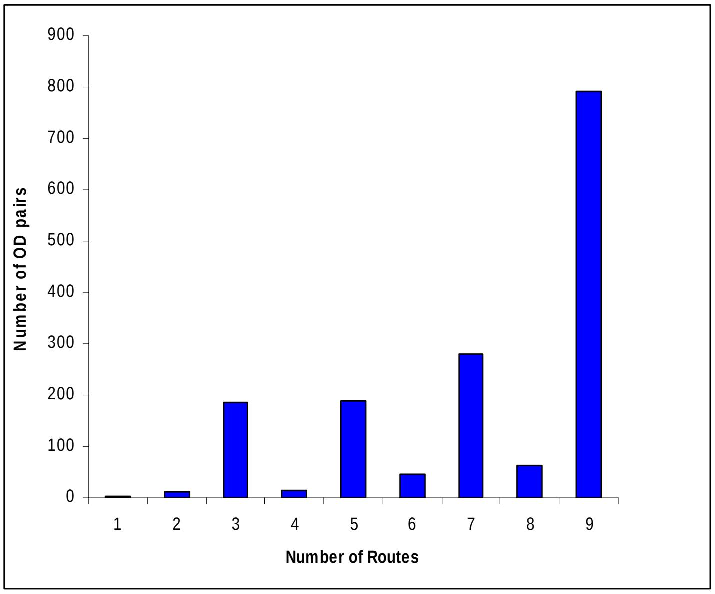

Figure 6. Average Travel Costs by Zones of Origin: Motorized Modes

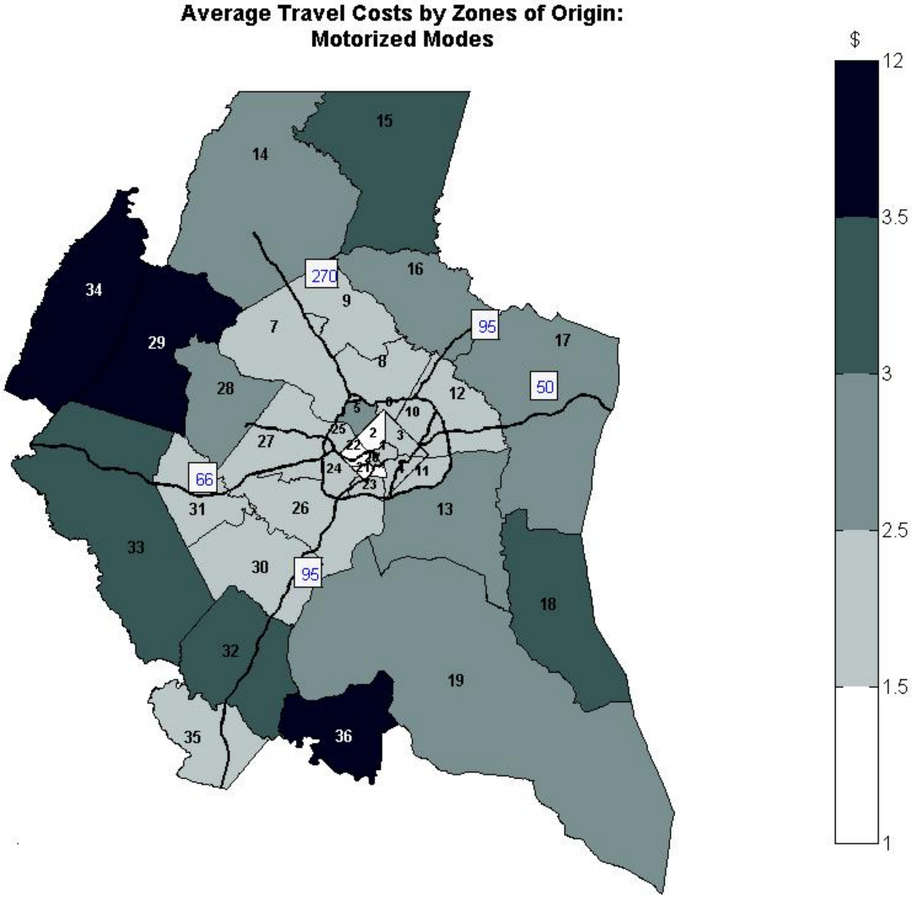

Figure 7. Average Monetary Costs of Travel by Zones of Destination: Motorized Modes

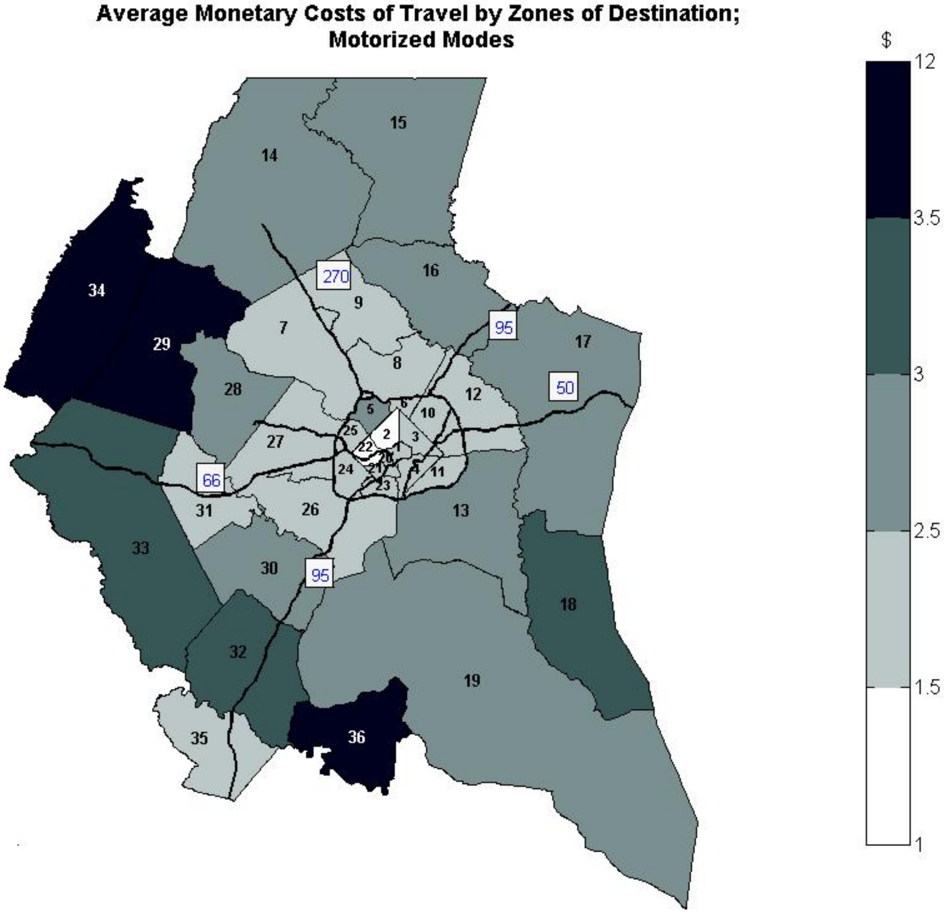

Figure 8. Average Travel Times by Zones of Destination: Motorized Modes

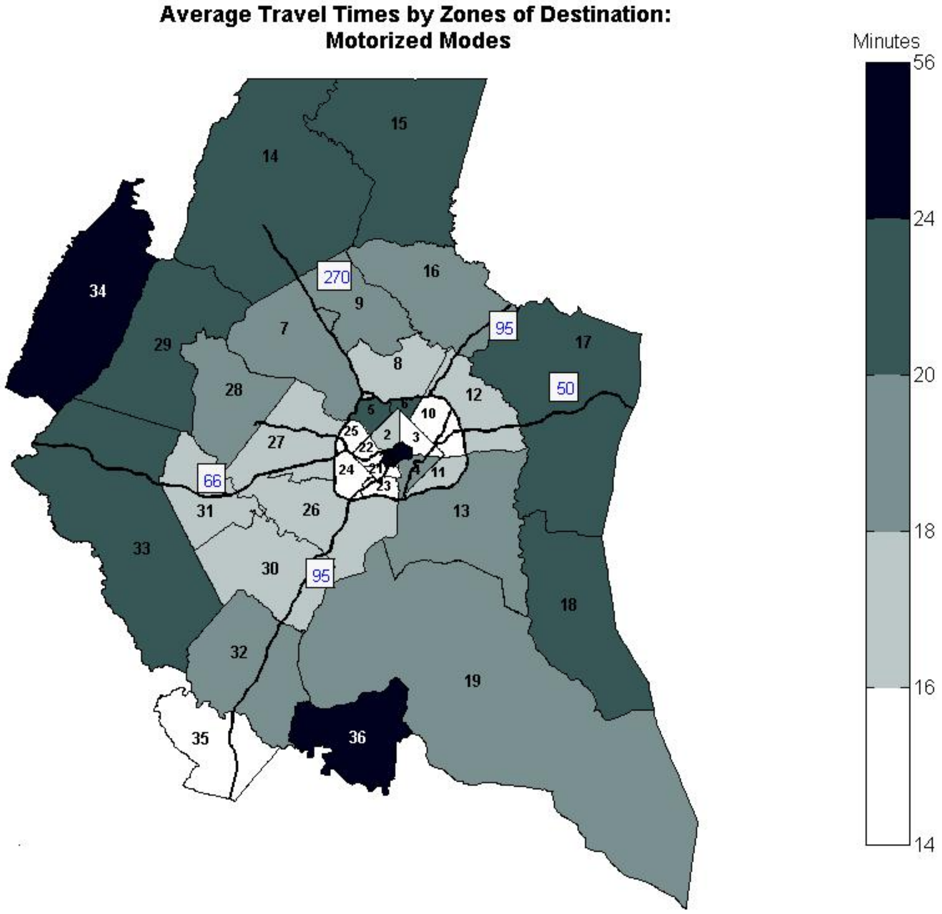

Figure 9. Average Travel Times by Zones of Origin: Motorized Modes