Virginia's Long-Range Multimodal
Transportation Plan
2007-2035

2035 SOCIOECONOMIC AND TRAVEL DEMAND FORECASTS FOR VIRGINIA AND POTENTIAL POLICY RESPONSES

Prepared for:
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Prepared by:
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ACRONYMS

ADT	average daily traffic
AVMT	annual vehicle miles traveled
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BTS	Bureau of Transportation Statistics
CO_2	carbon dioxide
DMV	Virginia Department of Motor Vehicles
DOAV	Virginia Department of Aviation
DPMT	daily passenger miles traveled
DRPT	Virginia Department of Rail and Public Transportation
DVMT	daily vehicle miles traveled
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GAO	U.S. Government Accountability Office
GDP	gross domestic product
HOT	high-occupancy toll
HOV	high-occupancy vehicle
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
MPO	metropolitan planning organization

NO_x	nitrogen oxide
NPA	NPA Data Services, Inc.
NVTC	Northern Virginia Transportation Commission
PDC	planning district commission
PMT	passenger mile traveled
RITA	Research and Innovative Technology Administration
SAFETEA-LU	Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users
TEA-21	Transportation Equity Act for the 21st Century
TOD	transit-oriented development
VEC	Virginia Employment Commission
VOC	volatile organic compounds
VMT	vehicle miles traveled
VPA	Virginia Port Authority
WMATA	Washington Metropolitan Area Transit Authority

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EXECUTIVE SUMMARY

Introduction

The *Code of Virginia* (§ 33.1-23.03) requires Virginia's Commonwealth Transportation Board to identify "all construction needs for all [modal] systems" every 5 years. In practice, the Commonwealth Transportation Board identifies these needs through Virginia's statewide multimodal transportation plan. The most current plan, known as VTrans2025, was finalized in 2004 (VTrans2025 Technical Committee, 2004). The plan will be updated in 2009, with the update being coordinated through Virginia's Office of Intermodal Planning and Investment and representatives of five statewide agencies: the Virginia Department of Aviation (DOAV), the Department of Motor Vehicles (DMV), the Virginia Department of Rail and Public Transportation (DRPT), the Virginia Department of Transportation (VDOT), and the Virginia Port Authority (VPA) (Office of Intermodal Planning and Investment, n.d.). This multimodal plan is known as VTrans2035.

To update this plan, the VTrans2035 Multimodal Advisory Committee sought four types of information for year 2035:

1. forecasts of socioeconomic activity, such as population, employment, household size, household income, and ratio of employment to households
2. forecasts of travel demand, such as daily vehicle miles traveled (DVMT) (for the highway mode); unlinked passenger trips (for the transit mode); and annual enplanements, i.e., the number of passengers boarding an aircraft (for the aviation mode)
3. information regarding changes in trends affecting the travel demand forecasts, such as potential changes in fuel costs and in the proportion of older drivers between now and 2035
4. potential policy responses to the challenges posed by these forecasts.

The purpose of this study was to provide the four types of information to the committee. The scope was limited to forecasts at the state or planning district commission (PDC) level in Virginia and included estimating the uncertainty associated with these forecasts.

Forecasts for 2035 in Virginia

Socioeconomic Forecasts

- Between 2010 and 2035, Virginia's population will grow by about one third from slightly more than 8 million to between 10.28 million (Virginia Employment Commission [VEC], 2008) and 10.93 million (NPA Data Services, Inc. [NPA], 2008). The proportion of persons age 65 and over will increase from about 12% to 19%, such that Virginia will have about 2 million individuals age 65+ in 2035 compared to about 1 million in 2010.

- Four PDCs will be responsible for between 76% (VEC, 2008) and 81% (NPA, 2008) of Virginia's population growth for the period 2010 through 2035. NPA (2008) showed that 2.34 million of the 2.87 million additional population will come from the following PDCs: Northern Virginia Regional Commission (Northern Virginia PDC) (1.23 million), Hampton Roads and Richmond Regional (0.41 million each), and George Washington (0.28 million). As discussed in the report, PDC boundaries were modified slightly to avoid the double counting of counties that are a member of more than one PDC.

- Between 2010 and 2035, total employment (wage, salary, and proprietor) will increase from 5.21 million to 7.75 million (NPA, 2008). As with population, much of this growth (84%) will be concentrated in four PDCs: Northern Virginia (1.28 million), Richmond Regional (0.37 million), Hampton Roads (0.35 million), and George Washington (0.15 million).

- Real household income (in 2000 dollars) will increase by about half, from $99,159 in 2010 to $148,948 in 2035. Thus, generally, each PDC is forecast to see its real household income grow between 38% and 60%.

- Population and employment growth rates by PDC between 2010 and 2035 will be more variable than household income growth rates (NPA, 2008; VEC, 2008). Population growth rates will vary between approximately 3% (Cumberland Plateau) and 73% to 80% (George Washington). Employment growth rates vary between 8% (West Piedmont and Southside) and 90% (George Washington).

- Although the average household income of each PDC is expected to grow by 38% to 60%, the 2010 incomes themselves will vary substantially. For example, the smallest average household income in 2010 ($56,222 in Lenowisco) will be less than half the largest average household income ($143,371 in Northern Virginia).

- Because population forecasts (NPA, 2008; VEC, 2008) were available only up to 2030, they were extended to 2035 using linear regression. When NPA data were used, the 95% prediction interval attributable to this regression was relatively tight (between 10.905 and 10.947 million). When VEC data were used, interval was larger (between 9.508 and 11.050 million). The reason for the difference is that the NPA data are available annually whereas the VEC data are available only on a decennial basis.

- Population forecasts extrapolated from NPA (2008) and VEC (2008) differed by 647,238 people (about 6% of the 2035 VEC forecast).

- As expected, discrepancies in population forecasts at the regional (PDC) level were greater than at the state level. For 2030, the statewide forecasts from different sources varied by approximately 491,000 (5% of the 2030 VEC forecast). For the same year, a summation of the absolute value of the difference in forecasts for each region was about 675,510 (7% of the 2030 VEC forecast).

- Statewide forecasts for 2025 in this report (9.7 million) differed from the high end of those made in 2003 (Miller, 2003) (9.3 million) by approximately 4%.

- In forecasts for 2010, only four PDCs—Hampton Roads, Richmond Regional, Roanoke Valley-Alleghany Regional Commission (Roanoke Valley-Alleghany PDC), and Northern Virginia—had wage and salary employment to household ratios above the forecast 2010 statewide ratio of wage and salary jobs to households, or 1.41. In forecasts for 2035, these continued to be the only PDCs with ratios above the forecast 2035 statewide ratio of 1.46.

Travel Demand Forecasts

- The DVMT forecast for year 2035 was between 321 and 345 million. The lower number was based on the 2035 population forecast from VEC (2008), and the higher number on the 2035 population forecast from NPA (2008). Both forecasts were based on the relationships between total DVMT and population between 1991 and 2007.

- These forecasts are similar to those in the literature, which suggested annual DVMT growth rates of 1.74% through 2010; 1.58% for 2011 through 2020; and 1.31% for 2021 through 2035 (Liu et al., 2007). A forecast based on this approach yielded a 2035 DVMT of 337 million.

- An upper forecast was determined based on a Virginia DVMT growth rate of 2.77%, which occurred between 1982 and 2007. This upper forecast was 484 million DVMT.

- It is possible to subdivide the state DVMT to the PDC level, as was done in this report; to the extent that population will influence DVMT, approximately 67% to 70% of this DVMT was attributed to four PDCs (George Washington, Hampton Roads, Northern Virginia, and Richmond Regional).

- Although the assumption that DVMT is proportionate to population comprises a useful guideline, DVMT is attributable to other factors, especially when the area of analysis is a region rather than a state. For example, in 2006, the George Washington, Hampton Roads, Northern Virginia, and Richmond Regional PDCs had 59.8% of the statewide measured DVMT and 64% of the statewide population. When both transit passenger miles traveled and DVMT were included, the travel share for the four PDCs increased to 60.2% of the state's combined transit passenger miles traveled and DVMT.

- The 2035 transit demand forecast was 352 to 360 million transit trips, which is almost double the 2007 value of 192 million trips. Most of these trips (60%) were attributable to the rail and bus service provided by the Washington Metropolitan Transit Authority in Northern Virginia.

- The estimate of 352 to 360 million transit trips was based on an assumed annual growth rate of 2.19% to 2.27% (which were the historical growth rates from 1991 through 2007; the range is due to uncertainty regarding some of these historical data). Had a higher rate been assumed, such as the annual growth rate of 4.07% for the period 1997 through 2007, the

2035 forecast would have been 587 million trips. Had a lower annual growth rate been assumed, such as the negative 0.65% during the period 1991 through 1997, a lower forecast of 160 million transit trips would have been expected, which would be a decrease from the 2007 value of 192 million trips.

- Virginia enplanements (passengers boarding an aircraft) are expected to increase from 25.6 million in 2007 to 56.7 million in 2035 based on expected national annual enplanement growth rates provided by the Federal Aviation Administration (FAA) (2008a). In 2007, most (95.7%) of Virginia's enplanements were at the Commonwealth's four largest airports: Dulles International Airport, Ronald Reagan Washington National Airport, Richmond International Airport, and Norfolk International Airport (FAA, 2008b).

External Influences Affecting Travel Demand Forecasts

A sensitivity analysis considered the impacts on DVMT of changes in personal income, population, fuel cost, and density. The sensitivity analysis also considered the impacts of fuel price (on transit trips) and economic conditions (on aviation enplanements). Because income data were available from one source (NPA, 2008) and because it was desired to use population data from the same source to increase data consistency, the sensitivity analysis used the following as a *baseline*: a 2035 population estimate of 10.93 million and a DVMT forecast of 345.4 million based on the 2035 population estimate. For transit, the sensitivity analysis used a baseline of 360 million trips based on extrapolation of growth trends from 1991 through 2007 based on information provided by Hill (2008). For aviation, the baseline was 56.7 million enplanements based on applying growth rates shown in FAA (2008a).

The results of this sensitivity analysis for DVMT, transit trips, and enplanements were as follows:

- A change in real fuel costs (unleaded gasoline) from the assumed \$2.80/gal to an amount as low as \$1/gal or as high as \$10.00/gal yielded between 402 million and 119 million DVMT based on published elasticities relating vehicle travel to fuel costs. (These forecasts deviated from the baseline value of 345 million DVMT by 16% and 66%, respectively.)

- A change in real household income growth between 2010 and 2035 from the assumed increase of 50.21% to an increase as low as 0.21% or as high as 100.21% yielded between 216 million and 474 million DVMT. (These forecasts deviated from the baseline DVMT by 37%.)

- An increase in density such that all new population growth between 2010 and 2035 was placed in the highest density PDC reduced DVMT to 332 million, which was a reduction of 4% from the baseline DVMT.

- The changes in DVMT described in the preceding three bullet items assumed average elasticities. As shown in Figure 13 of the report, the elasticities in the literature varied substantially for the cases of the effect of (1) fuel costs and (2) income on travel demand. Figure 13 shows that the variation in elasticity for the effect of density on travel demand was less than that of fuel costs or income on travel demand.

- A change in real fuel costs from the assumed value or \$2.80/gal to a value as low as \$1/gal or as high as \$10/gal yielded between 332 million and 471 million unlinked transit trips. These forecasts deviated from the baseline value of 360 million trips by 8% and 31%, respectively. (The baseline fuel cost of \$2.80/gal was used in the sensitivity analysis because transit data were last available in 2007.)

- The aviation forecast of 56.7 million enplanements in 2035 is highly dependent on economic conditions, the price of fuel, the applicability of national projections to Virginia, and the extent to which growth rates projected to year 2025 (FAA, 2008a) can be extended to year 2035. Extrapolation of a low forecast scenario from the literature (FAA, 2008a) and the use of higher Virginia large domestic carrier enplanement growth rates for the period 2000 through 2007 (FAA, 2008b) suggested a low 2035 forecast of 26.8 million enplanements and a high 2035 forecast of 62.2 million enplanements.

Identification of Potential Policy Responses to Challenges Suggested by Forecasts

One criterion was used to identify potential policy responses to challenges suggested by the forecasts: the policy response had to require coordination across at least two of the following areas: highway travel, transit travel, aviation travel, land development, and passenger safety. The reason for this was that the Office of Intermodal Planning and Investment, which houses VTrans2035, was created to “encourage the coordination of multimodal and intermodal planning across the various transportation modes within the commonwealth” (Office of Intermodal Planning and Investment, n.d.). Thus, although a wide variety of policy responses could be implemented by an individual agency; this report focused on policy responses that appeared to require coordination across two or more agencies.

Through the use of this criterion, four potential policy responses were identified:

1. Encourage increased density at select urban locations to reduce CO_2 emissions.

2. Use cost-effectiveness as a criterion to select project-level alternatives for achieving a particular goal.

3. Identify policy initiatives to serve increased demographic market segments.

4. Quantify the economic harm of general aviation airport closures.

Determination of Impact of Potential Policy Responses

Policy Response 1: Encourage Increased Density at Select Urban Locations to Reduce CO_2 Emissions

For the analysis of the impact of this policy response to reduce CO_2 emissions, state level encouragement for four PDCs to increase density in their more urban areas rather than in their more rural areas was examined.

The findings were as follows:

- The four PDCs where most (76% to 81%) of the state's 2010 to 2035 population growth will occur were considered: George Washington, Hampton Roads, Northern Virginia, and Richmond Regional.

- In each PDC, an increased density scenario was considered where growth between 2010 and 2035 was diverted to the two highest density areas of the PDC. For example, in George Washington, growth was diverted to the City of Fredericksburg rather than to King George County.

- The density increase reduced DVMT by 6.11% (George Washington), 0.19% (Hampton Roads), 0.56% (Richmond Regional), and 6.82% (Northern Virginia). This reduced 9.1 million DVMT, which constituted a 2.6% reduction from the baseline value of 345.4 million DVMT.

- On an annual basis, this DVMT reduction would eliminate 1.507 million metric tons of CO_2, based on the baseline DVMT of 345.4 million, the supporting population estimates from NPA (2008), and factors from the literature (Feigon et al., 2003) relating CO_2 emissions to DVMT. A reduction of 1.563 million metric tons is estimated if other assumptions regarding population (VEC, 2008), emissions factors (Ponticello, 2008), and baseline DVMT (e.g., 321.2 million DVMT) are used instead.

Policy Response 2: Use Cost-effectiveness As a Criterion to Select Project-Level Alternatives for Achieving a Particular Goal

The case study used in the analysis of this policy response compared seven modally different alternatives for reducing NO_x emissions for an example congested corridor. The alternatives included the support of transit-oriented development (TOD), increased transit hours of operation, a reduction in transit fares, the provision of a parking subsidy to encourage carpooling, construction of a reversible high-occupancy vehicle (HOV) / high-occupancy toll (HOT) lane (with and without trucks), and improved access management. This analysis yielded two findings:

1. The cost for reducing 1 kilogram of NO_x ranged from \$1,221 for the most effective alternative to \$4,181 for the least effective alternative—a ratio of 3.42.

2. When the assumptions were changed, such as for the cost for the parking subsidy or for HOV/HOT lane construction, a different alternative became the most cost-effective but the ratio of the least to most cost-effective alternative was similar and also large (ratio of 3.37).

The comparison implied that gains in cost-effectiveness can be realized if decision makers are able to choose alternatives, regardless of mode, based solely on cost-effectiveness with regard to achieving a particular goal. The particular goal chosen in the analysis of this policy response was reduction of NO_x emissions, but Virginia decision makers could select other goals.

Policy Response 3: Identify Policy Initiatives to Serve Increased Demographic Market Segments

To investigate the impact of this policy response, the demographic group of Virginia's population age 65 and older was used in a case study. The number of Virginians age 65 and over will roughly double from 1 million in 2010 to 2 million in 2035. Two findings resulted from the case study to provide mobility alternatives for the larger proportion of the population age 65 or older:

1. *At least four diverse alternatives merit further consideration.* One alternative is well known and is being implemented or considered in Virginia: age-friendly roadway designs (e.g., left turn lanes with positive offsets). Two other alternatives—physical rehabilitation (e.g., physical and cognitive therapies that will also help drivers maintain their driving skills) and carefully targeted programs to prevent driver cessation—may be less well known. The fourth alternative—considering the mobility needs of older residents at the land development stage—is outside the purview of the state transportation agencies. A review of the literature suggested that although all four alternatives require further research, all four appear to have at least some merit and should be considered as additional information about their efficacy becomes available.

2. *To be successful, it appears that the alternatives need to be carefully targeted.* For example, anecdotes from Rosenbloom and Herbel (2008) offered a compelling case for targeting programs to encourage continued driving to women. According to these anecdotes, as a result of pressure from their spouse, some women stop driving even though they can still drive safely; it is then harder for these women to re-start driving later because of the break in their driving experience.

This policy response illustrates how to consider just one market segment that will have increased importance in 2035. Other market segments, such as immigrants arriving in the United States or transit-dependent populations that relocate to areas without transit services because of urban revitalization efforts, may also merit further study.

Policy Response 4: Quantify the Economic Harm of General Aviation Airport Closures

The analysis of this policy response was to quantify the economic harm that would result from the closure of select general aviation airports that are at risk for closure or operations restrictions in order to protect Virginia's investment in aviation infrastructure.

Airports generate economic benefits through direct impacts (e.g., airport employee wages), airport-dependent impacts (e.g., businesses depend on the airport for essential services, such as executive travel to visit a manufacturing facility, where such impacts may include taxes paid by such businesses), and multiplier effects (DOAV, 2006a). These economic benefits were estimated to be approximately $18 billion in 2007 (Bureau of Labor Statistics, 2008; DOAV, 2006a) and may grow to between $19 billion and $43 billion in 2035 depending on the number of enplanements.

Although these enplanements are affected by numerous factors beyond Virginia's control (economic conditions, the threat of terrorism), one factor that Virginia may influence is the extent to which smaller general aviation airports are kept open. General aviation airports may be under pressure to close or restrict operations, either because the airport itself may be used for other purposes (e.g., residential development) or because of concerns about airport noise (DOAV, 2006b). Virginia's general aviation airports may have contributed $3.66 billion (in 2007 dollars) in economic benefits (e.g., output, employment, and earnings) (Allen et al., 2006; Bureau of Labor Statistics, 2008).

This policy response may be a productive area for future exploration to the extent that (1) local service airports are an essential component of the aforementioned economic activity, and (2) such information could be used to support transportation/land use coordination (DOAV, 2006b), such as appropriate development of land adjacent to airports. Such work would build on Virginia-specific economic impact work that has already been conducted (DOAV, 2006a) and would focus on the impact of closures as was done by Weisbrod (1990).

Limitations of Macroscopic Analyses

There are several limitations to the macroscopic analyses presented here that can be resolved only as more detailed data are collected. These limitations include the manner in which statewide travel demand estimates are derived, the extent to which the elasticity-based assumptions will hold over time, the inability to quantify the impacts of Policy Responses 3 and 4 at present, and the manner in which the policy responses are implemented. For example, with Policy Response 1, the state does not have the authority to mandate increased density: it can only encourage metropolitan planning organizations or PDCs to consider this response, which they in turn can encourage but not mandate through zoning policies, comprehensive plans, and possibly the provision of technical assistance.

Conclusions

- *Socioeconomic activity and travel demand in Virginia are expected to increase from 2010 to 2035*. The best estimates for these increases are as follows:

  — Population: 28.3% (based on VEC data) or 35.6% (based on NPA data)
  — Employment: 48.9%
  — Household income: 50.21% in 2000 dollars
  — Employment to household ratio: 3.6% (statewide) with some higher increases (e.g., Northern Virginia with 7.3%), some lower increases (e.g., 2.2% in George Washington Regional), and some decreases (e.g., –10.3% in Rappahannock-Rapidan); these ratios exclude proprietor employment
  — DVMT (highway): 35.6% (based on the VEC population) or 44.8% (based on the NPA population)
  — Unlinked passenger trips (transit): 75.47%
  — Annual enplanements (aviation): 103.5%.

  Note also that the average household size will decrease by 3.1%.

  These best estimates depend on a wide variety of assumptions and may be replaced by a range. For example, the range of annual enplanements for year 2035 relative to 2007 is between 5% and 143% depending on GDP growth.

- *Although DVMT will increase, the annual rate of increase between 2010 and 2035 will be less than it was between 1982 and 2007*. A model predicting 2035 Virginia DVMT as a function of population forecast between 321 and 345 million DVMT, depending on which 2035 population is used. The application of low growth rates suggested by some literature yielded 337 million DVMT. All three estimates are substantially lower than what would result from the extension of historical Virginia DVMT growth rates between 1982 and 2007 (483.6 million DVMT).

- *Although statewide forecasts of DVMT, transit trips, and aviation enplanements have some uncertainty because of population, the uncertainty attributable to other factors, such as growth in household income, is larger*. Population uncertainty affected the 2035 DVMT estimate by a modest amount (321.2 to 345.4 million), whereas a change in household income caused a wider change in the forecast (113.3 to 529.0 million).

- *Although the four policy responses developed in this study may have merit, there is no "silver bullet*." For example, to the extent that density is a surrogate for other factors such as pleasantness of walking and proximity of destinations that may reduce automobile trip length or frequency, an increase in population density in select high-density jurisdictions may eliminate 1.507 million metric tons of CO_2 per year, based on the elimination of 9.1 million DVMT, which is 2.6% of the statewide 2035 DVMT. This change is smaller than changes in two different 2035 statewide population estimates (7.0% of DVMT), an increase in fuel costs to $10/gal (66% of DVMT), or elimination of the anticipated 50% increase in real household incomes between 2010 and 2035 (37% of DVMT).

- *The policy responses suggest that the challenges facing Virginia may possibly be addressed more effectively if alternatives can be selected based on their ability to achieve one or a small number of goals*. Policy Response 2 demonstrated that for a given goal, such as emissions reduction, the most cost-effective alternative may come from diverse areas (land use, highway construction, highway operations, transit construction, or transit operations) and thus flexibility to choose an alternative without modal restrictions may be beneficial. In the case study examined, the cost of the "best" alternative was less than one third that of the "worst" alternative—but site-specific information is needed to determine which alternative is best. This information is not necessarily available at the time of programming.

- *The range of potential policy responses is diverse in that different modes and different disciplines are required*. For the case study in Policy Response 3—identify policy initiatives to serve persons age 65 and over—included making roadway improvements amenable to older drivers and developing techniques, such as physical therapies and carefully targeted driver encouragement programs, that require a variety of skills.

- *Although DVMT is more sensitive to income than to fuel costs (Pickrell and Schimek, 1998), the analysis in this report suggests that changes in fuel cost may have a greater impact on fuel-based DVMT than changes in household income*. The explanation is that fuel costs between 2010 and 2035 could vary by as much as an order of magnitude (e.g., the high value of $10/gal of unleaded gasoline is *10 times* the low value of $1/gal) whereas household income is not assumed to have quite as large a range. Historical data suggest that fuel costs are more volatile than income.

Recommendation

This report found that four policy responses to the challenges posed by the changes facing Virginia by year 2035 have potential merit relative to the do-nothing case. Because this report did not *prove* that each policy response would be an effective use of resources, the four policy responses are only recommended *for consideration* at this point in time. These policy responses are:

1. *Encourage increased density at select urban locations to reduce CO_2 emissions*. The potential benefit of this response is a reduction in DVMT (a value of 2.6% was computed in this report). The potential disadvantage is that other factors, such as fuel price (and, as a consequence, policies based on fuel price), may have a greater impact.

2. *Use cost-effectiveness as a criterion to select project-level alternatives for achieving a particular goal*. The potential benefit of this response is an increase in cost-effectiveness (a ratio of about 3.37 to 3.42 between the least and most cost-effective project in this report was calculated). The potential disadvantage is that obtaining agreement on a single goal for a particular project can be difficult.

3. *Identify policy initiatives to serve increased demographic market segments*. The potential benefit of this response is identification of creative strategies to increase

mobility; for example, given the expected doubling of persons age 65 and older by 2035 and the expected growth in DVMT, the strategy of enabling older drivers to continue driving (through traffic engineering and targeted educational campaigns) appears to have merit. The potential disadvantage of this response is that the costs of the various components of this strategy have not been assessed to determine which components are the most effective.

4. *Quantify the economic harm of general aviation airport closures.* The potential benefit of this response is that the results of such a study might enable Virginia to preserve components of its air transport system. The potential disadvantage of this response is the cost of such a study.

2035 SOCIOECONOMIC AND TRAVEL DEMAND FORECASTS FOR VIRGINIA AND POTENTIAL POLICY RESPONSES

INTRODUCTION

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To update this plan, the VTrans2035 Multimodal Advisory Committee sought four types of information for year 2035:

1. forecasts of socioeconomic activity, such as population, employment, household size, household income, and ratio of employment to households
2. forecasts of travel demand, such as daily vehicle miles traveled (DVMT) (for the highway mode); unlinked passenger trips (for the transit mode); and annual enplanements, i.e., the number of passengers boarding an aircraft (for the aviation mode)
3. information regarding changes in trends affecting the travel demand forecasts, such as potential changes in fuel costs and in the proportion of older drivers between now and 2035
4. potential policy responses to the challenges posed by these forecasts.

PURPOSE AND SCOPE

The purpose of this study was to provide the four types of information sought by the VTrans2035 Multimodal Advisory Committee for Virginia: (1) socioeconomic forecasts, (2) travel demand forecasts, (3) changes in trends affecting the travel demand forecasts, and (4) possible policy responses to the challenges posed by these forecasts.

The scope was limited to forecasts at the state or planning district commission (PDC) level in Virginia and included estimating the uncertainty associated with these forecasts.

METHODS

Six tasks were completed to achieve the study objectives:

1. Develop socioeconomic forecasts for year 2035.
2. Develop travel demand forecasts for year 2035.
3. Identify external influences affecting the travel demand forecasts.
4. Identify potential policy responses to the challenges suggested by the forecasts.
5. Determine the impacts of these policy responses.
6. Revise the analysis based on comments from the Multimodal Advisory Committee.

Development of Socioeconomic Forecasts for Year 2035

Forecasts for population, employment, household size, household income, and employment to household ratios were developed for year 2035 at the geographic level of a PDC. The PDC level was chosen because a forecast for a larger area (such as a PDC) is more accurate than one for a smaller area (such as a jurisdiction). With Virginia divided into 21 PDCs (see Figure 1), a PDC is sufficiently disaggregate to show key differences in population and employment that are likely to affect travel demand by 2035. Although some jurisdictions and some PDCs have forecasts for various years, such as the Hampton Roads PDC, which noted that its population for year 2034 is projected at 1,575,348 (Whaley, 2007), it does not appear to be the case that all PDCs or jurisdictions have long-range projections for the same future year.

Five steps were followed to develop socioeconomic forecasts.

1. *Obtain available data*. A primary source for projections of population, employment, household size, and household income for each year for various regions through year 2030 was a private vendor: NPA Data Services, Inc. (NPA) (2008). Publicly available data, such as population projections for year 2030 (Virginia Employment Commission [VEC], 2008) and land area (Weldon Cooper Center for Public Service, 2003) were also obtained.

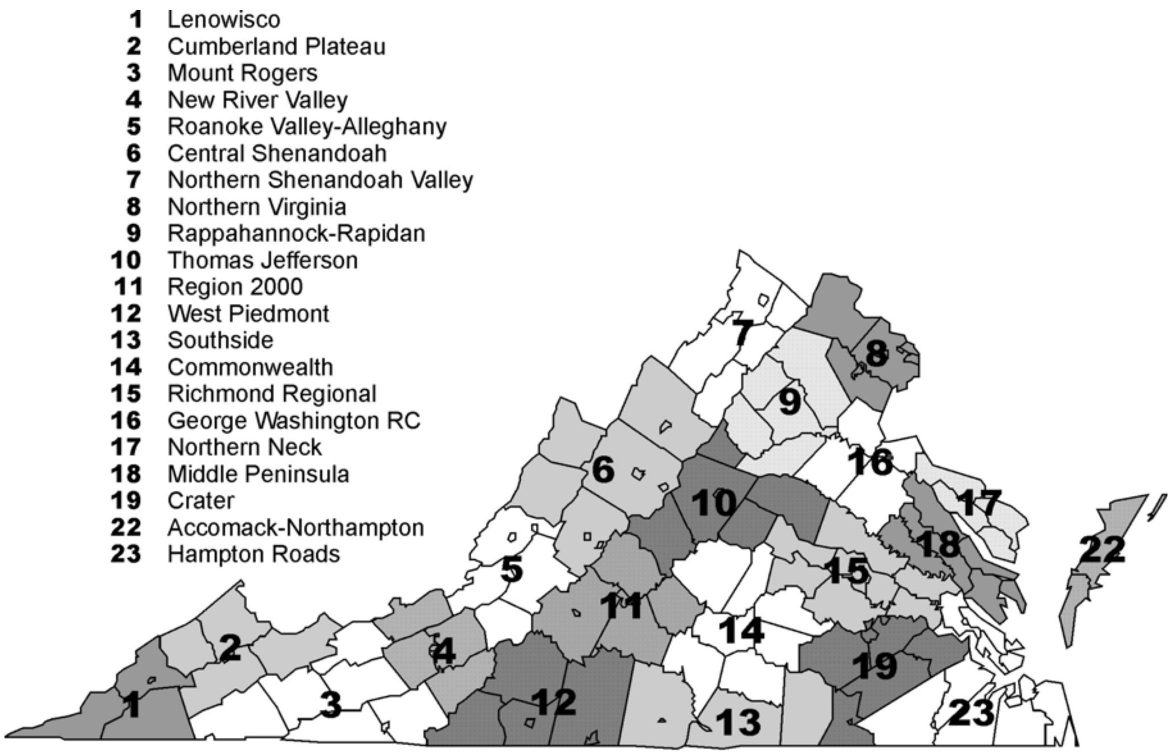

Figure 1. Virginia's 21 Planning District Commissions.
The numbers indicate the number of the particular PDC. Virginia does not have PDCs numbered 20 or 21 because in 1990, PDC 23 was created by merging PDCs 20 and 21 (Beamer, 1994).

2. *Organize data by PDC.* Some data were available at the jurisdiction level (e.g., Accomack County), and some data were available at the regional level (e.g., Augusta County combined with the cities of Staunton and Waynesboro). These data were organized roughly by PDC with the following caveat: in five instances, one county is included in more than one PDC. For example, Gloucester County is a member of the Hampton Roads PDC (Hampton Roads PDC, 2008) and the Middle Peninsula PDC (Middle Peninsula PDC, n.d.). To avoid double counting any counties, each county was assigned to one PDC in a manner consistent with that used elsewhere (Weldon Cooper Center for Public Service, 2008).

3. *Extrapolate forecasts for year 2030 to year 2035 by region.* Linear regression (Eq. 1) was used to extrapolate the forecasts. For the VEC data, the 2035 value (VEC 2035) was based on 2010, 2020, and 2030 data as these were the only values available. For the NPA data, the 2035 value (NPA 2035) was extrapolated based on the change for the period 2025 to 2030, as suggested by Terleckyj (2008). In Eq. 1, Y_i is the dependent variable (e.g., population for a given PDC for a given year), a and b are coefficients determined from linear regression, and X_i is the independent variable denoting the year.

$$Y_i = a + b(x_i) \qquad \text{[Eq. 1]}$$

The *Code of Virginia* (§ 60.2-113.6) indicates that the VEC is to "[p]repare official short and long-range population projections for the Commonwealth for use by the General Assembly and state agencies with programs which involve or necessitate population projections." Readers who need a single VEC estimate of the 2035 population may choose the midpoint VEC 2035 value based on this methodology.

4. *Estimate uncertainty due to extrapolation from 2030 to 2035.* Hillier and Lieberman (2001) provided a methodology for estimating a confidence interval for a prediction from linear regression (i.e., prediction confidence interval). This formula is shown in Eq. 2, where Y_c is the best forecast for year 2035 and the remaining variables are determined from the linear regression in Eq. 1 as follows. For the NPA data, n is the number of years (hence n = 6 for years 2025-2030); x_i and y_i denote year and population for the period 2025 through 2030; Y_i is the computed population for years 2025 through 2030; and p is the number of independent variables (hence p = 1). For the VEC data, n = 3 for years 2010, 2020, and 2030 and x_i and y_i correspond to those years and populations.

$$Y_c \pm \left(t_{0.025,n-2}\right)\left(\sqrt{1+\frac{1}{n}+\frac{\left(2035-x_{avg}\right)^2}{\sum_{i=1}^{n}\left(x_i-x_{avg}\right)^2}}\right)\left(\sqrt{\frac{\sum_{i=1}^{n}\left(Y_i-y_i\right)^2}{n-p-1}}\right) \quad \text{[Eq. 2]}$$

5. *Estimate uncertainty due to differences in forecast methodologies.* When two sources provided the basis for a forecast, the values were compared. For example, for each PDC, population projections from 2030 from VEC were compared to population projections for 2030 from NPA. This difference may be viewed as an empirical confidence interval, analogous to the prediction (i.e., statistical) confidence interval shown in Eq. 2.

Development of Travel Demand Forecasts for Year 2035

Travel demand was forecast for three modes: highway (as DVMT), transit (as unlinked passenger trips), and aviation (as enplanements).

Highway Forecasts

Four estimates of statewide DVMT were obtained.

1. *DVMT based on VEC population.* For the period 1991 through 2007, regression models comparable to those shown in Eq. 3, where $DVMT_i$ is the DVMT for a given year and b is a coefficient for population, were developed. Then, the VEC 2035 population was used in Eq. 3 to obtain a single statewide forecast. The period 1991 through 2007 was chosen because the ratio between population and DVMT was

relatively stable; further, such a period was consistent with the availability of data for the transit forecast.

$$DVMT_i = a + b(population_i) \qquad [Eq.\ 3]$$

2. *DVMT based on NPA population.* Eq. 3 was used again to estimate DVMT for the NPA 2035 population. Population, employment, households, years, income, and DVMT are all highly correlated such that Eq. 3 explains 96% of the annual variation in DVMT.

3. *Low DVMT growth.* The literature suggests DVMT growth rates of 1.74% to 2% for the period 2001 through 2025 (Polzin, 2006). A Pennsylvania model based on changes in households, income, and lane-miles in that state suggested lower growth rates for future years (attributable in part to household growth rates decreasing and the portion of the population age 65+ increasing): 1.74% through 2010, 1.58% for 2010 through 2020, and 1.31% for 2020 through 2030 (Liu et al., 2007). The lower of these rates was applied to 2007 DVMT for the period 2007 through 2035.

4. *High DVMT growth.* This is a high forecast that presumes an annual growth rate of 2.77% per year, which was the case for the period 1982 through 2007. This period was chosen based on the advice of an experienced forecaster of national DVMT (Crichton, 2008) who further suggested that for a high estimate of DVMT, it might be appropriate to consider a 25-year history, which could show possible long-term growth but not the dramatic increases in DVMT evident in the 1960s.

DVMT for each PDC was then estimated with each of the four methods. The proportion of DVMT to each PDC was determined from the proportion of 2035 population in each PDC. For Estimate 1, the VEC 2035 population forecasts were used, and for Estimates 2 through 4, the NPA 2035 population forecasts were used.

Transit Forecasts

Statewide transit demand was estimated based on historical transit growth rates from 1991 to 2007 in Virginia (Federal Transit Administration [FTA], 2008b; Hill, 2008; McGavock, 2008; Taube, 2007). Variations in these rates, such as the decrease in transit usage between 1991 and 1997 and the increase thereafter, were used to estimate a range of possible values of transit demand for 2035. Transit demand was measured as the number of unlinked passenger trips.

Aviation Forecasts

Statewide aviation demand was estimated using a different method than those used for highway and transit. The Federal Aviation Administration (FAA) (2008a) forecasts national annual rates of growth in enplanements for three categories of aviation travel: (1) domestic enplanements by mainline carriers (2.5%); (2) domestic enplanements by regional carriers (3.8%); and (3) international enplanements by U.S. carriers (4.6%). Although FAA (2008b) provides total enplanements at Virginia airports for years 2001 through 2007, these enplanements are not divided into the three categories used by FAA (2008a). However, these categories were used by the Bureau of Transportation Statistics (BTS) (2002) for nine of Virginia's airports. For these nine airports, therefore, Eq. 4 was used to develop 2035 enplanements:

$$\begin{aligned}\text{2035 Enplanements} &= (\text{2007 Enplanements})(\text{Proportion Of Enplanements by Foreign Carriers})(1.046)^{(2035-2007)} \\ &+ (\text{2007 Enplanements})(\text{Proportion Of Enplanements by Large Carriers})(1.025)^{(2035-2007)} \\ &+ (\text{2007 Enplanements})(\text{Proportion Of Enplanements by Small Air Carriers or Air Taxis})(1.038)^{(2035-2007)}\end{aligned} \quad \text{[Eq. 4]}$$

At Virginia's smaller airports for which BTS data are not available, it was assumed that all air traffic was regional, and thus Eq. 4 simplifies to Eq. 5.

$$\text{2035 Enplanements} = (\text{2007 Enplanements})(1.038)^{(2035-2007)} \quad \text{[Eq. 5]}$$

Of note is that the FAA forecasts are developed for the nation as a whole through year 2025 whereas Eqs. 4 and 5 were used to generate Virginia-specific forecasts through year 2035.

Identification of External Influences Affecting Travel Demand Forecasts

External Influences Affecting Highway Forecasts

If fuel costs, income, or land use changes in an unexpected fashion, DVMT should also change. To examine how changes to these three factors might influence DVMT, published values of elasticity (i.e., the percent change in DVMT attributed to a 1% change in the factor of interest, such as fuel cost, income, or density) were applied to the four DVMT forecasts noted previously as follows.

1. *Estimate the impact on DVMT of a change in fuel costs from a low value of $1/gallon to a high value of $10/gallon in year 2035.* The low value of $1 was chosen after a review of the literature suggested that the "electrical equivalent" of a gallon of fuel could be about $1 dollar if battery technology could make electric cars feasible for everyday use ("The End of the Petrol Head," 2008). The high value of $10 was chosen based up a review of Strobel (2008), who discussed the possibility of such higher prices. For each of these fuel costs, long term elasticities of –0.19 to –0.32 (Pickrell and Schimek, 1998) were used. (These long-term elasticities matched those given in a literature review by Sinha and Labi [2007] of –0.15 in the short run and –0.32 in the long run.) (The assumed fuel cost was $2.80 based on 2007 figures.)

2. *Estimate the impact on DVMT of an increase in real household income (between 2010 and 2035) from a low value of 0.0021% to a high value of 100.21%.* The assumed increase was 50.21% in real household income, and elasticities were varied between 0.10 and 0.65. These income elasticities were based on a review of the literature. Wadud et al. (2008) suggested a mean income elasticity of 0.34, comparable to that of Pickrell and Schimek (1998) who suggested elasticities of 0.35

to 0.37. The literature also suggested substantial variation in these elasticities; for example, Wadud et al. (2008) noted the income elasticity for urban households with a single vehicle and multiple workers was 0.304, whereas the elasticity for rural households with multiple vehicles and one or no workers was 0.445. Hess et al. (2008) noted that the modeling approach caused elasticities to vary between 0.08 and 0.40 but generally appeared to discourage the lower value. Other income elasticities included 0.1 to 0.4 (Froehlich, 2008), 0.646 (Choo et al., 2007), and 0.64 (Zhang and McMullen, 2008).

3. *Estimate the impact of increased density on DVMT.* DVMT is influenced by density to the extent that density is a surrogate for other factors such as transit availability, pleasantness of walking, mix of land uses, and closeness of destinations, that could reduce the frequency or duration of automobile trips. The impact of placing all additional population growth between 2010 and 2035 in the PDC with the greatest density was calculated; DVMT estimates were modified using two elasticities: a lower bound of –0.05 (Ewing and Cervero, 2001) and an upper bound of –0.29 (calculated from information by Sun et al., 1998).

The impact of density on DVMT as calculated yields an optimistically large DVMT reduction, since with a constant population, a net increase in density in one PDC will yield lower densities in other PDCs. The NPA (2008) dataset was used for these analyses because it provided a single source for two types of socioeconomic data required: population and household income.

External Influences Affecting Transit Forecasts

A method comparable to that used for highway forecasts was used to assess the impact of increased fuel costs on transit. The cross-elasticity of transit with respect to fuel costs (–0.12 based on Litman [2007]) was used to determine how changes in fuel costs between $1/gal and $10/gal may influence transit use.

External Influences Affecting Aviation Forecasts

Because aviation demand is highly dependent on economic growth, the impact of a change in the gross domestic product (GDP) on enplanements was calculated. FAA (2008a) reported the results of changing just one factor—economic growth. In that report, the Office of Management and Budget expected U.S. GDP to grow at 2.9% per year between 2007 and 2010, whereas a consulting firm (Global Insight) forecast an average annual GDP growth rate of 2.5%. FAA (2008a) found that by assuming the lower GDP growth rate of 2.5%, the 2010 enplanements were forecast to be 7.7% lower than the 2010 forecast that assumed a GDP growth rate of 2.9%. This decrease was used as the basis for calculating a low Virginia enplanement forecast.

This low forecast was developed by projecting large domestic, regional domestic, and international enplanements from 2007 to 2010 by the FAA baseline projections (2.5%, 3.8%, and

4.6%), reducing these 2010 projections by 7.7%, deriving the average annual growth rate for the period 2007 through 2010, and using this annual growth rate to develop 2035 projections.

A high Virginia enplanement forecast was developed by assuming large domestic enplanements would grow to 2035 at the annual rate in Virginia for the period 2000 through 2007 (2.97%) rather than FAA's baseline forecast (2.5%). Because the Virginia 2000 through 2007 annual growth rates for regional enplanements (2.95%) and international enplanements (2.91%) were *lower* than the FAA projections of 3.5 and 4.6%, the FAA projections for regional and international enplanements were used to develop the high forecast.

Identification of Potential Policy Responses to Challenges Suggested by Forecasts

One criterion was used to identify potential policy responses to challenges suggested by the forecasts: the policy response had to require coordination across at least two of the following areas: highway travel, transit travel, aviation travel, land development, and passenger safety. The reason for this was that the Office of Intermodal Planning and Investment, which houses VTrans2035, was created to "encourage the coordination of multimodal and intermodal planning across the various transportation modes within the commonwealth" (Office of Intermodal Planning and Investment, n.d.). Thus, although a wide variety of policy responses could be implemented by an individual agency; this report focused on policy responses that appeared to require coordination across two or more agencies.

Through the use of this criterion, four potential policy responses were identified:

1. Encourage increased density at select urban locations to reduce CO_2 emissions.
2. Use cost-effectiveness as a criterion to select project-level alternatives for achieving a particular goal.
3. Identify policy initiatives to serve increased demographic market segments.
4. Quantify the economic harm of general aviation airport closures.

Determination of Impact of Potential Policy Responses

Policy Response 1: Encourage Increased Density at Select Urban Locations to Reduce CO_2 Emissions

This policy response encourages *individual PDCs* to increase density in their most urban areas in order to reduce DVMT, and hence CO_2 emissions, in the PDC as a whole. This policy response was selected because it does not change the 2035 population in each PDC but rather moves anticipated 2010-2035 growth from less dense to more dense locales within each PDC.

This impact of this policy response was determined through four steps:

1. For the four most populous PDCs, estimate the density in each jurisdiction that will result if (1) 2035 population growth proceeds as forecast, and (2) if all population

growth between 2010 and 2035 in the PDC is diverted to the two most densely populated jurisdictions in that PDC.

2. For each jurisdiction, estimate the annual vehicle miles traveled (AVMT) from national data (Ross and Dunning, 1997), which shows how AVMT per person varies as a function of density. (For example, the average AVMT per person is 10,560 for densities of less than 250 people/mi^2 but 9,762 for densities between 250 and 999 people/mi^2.) Perform this calculation twice: once for Case 1 (the baseline 2035 densities) and once for Case 2 (the increased population densities). Then, subtract the AVMT for Case 2 from that of Case 1.

3. Apply the percentage reductions in AVMT noted in Step 2 to the DVMT estimates for each PDC.

4. Compute the change in CO_2 emissions that would result from this change in DVMT using composite emissions factors from the literature (Feigon et al., 2003).

The reason for the use of density-AVMT relationships in Step 2 is that these were expected to give a more accurate assessment of the impact of density on travel than the elasticity concepts, because an increase in urban density should achieve greater reductions than an increase in suburban density (Stone et al., 2007). Thus, the density-AVMT relationships in Step 2 should capture the impacts of density on DVMT more precisely than an approach that uses elasticities. However, the AVMT values in Step 2 are national averages whereas the DVMT estimates mentioned in Step 3 are specific to Virginia. Thus, Step 2 indicates how a change in density yields a percentage change in DVMT and Step 3 applies these percentages to Virginia-specific DVMT values.

Policy Response 2: Use Cost-effectiveness As a Criterion to Select Project-Level Alternatives for Achieving a Particular Goal

Overview

This policy response is to enable Virginia decision makers to select project-level alternatives, such as improved transit service, highway expansion, or operational improvements, based solely on cost-effectiveness for achieving a particular goal. Although cost-effectiveness is routinely a consideration at present, there are two constraints on complete adoption of such an approach. The first constraint is the funding source: it is not always possible to shift roadway construction funds to transit or vice-versa. The second constraint is that transportation improvements must satisfy multiple goals relating to safety, economic development, mobility, environmental consequences, and quality of life rather than just one particular goal.

Case Study

To determine the impact of selecting an alternative based solely on cost-effectiveness, a case study of the goal of reduced ground level ozone for 2035 was selected. A sample scenario and seven alternatives for achieving the goal were used for the analysis.

The sample scenario is a 4-mile congested arterial facility with 32,250 vehicles per commuting day. On such days, there are 5 peak hours, and during each peak hour the traffic volumes are as follows: 3,000 autos, 240 heavy duty diesel trucks, and 3 buses each with 20 passengers per bus. During these congested conditions, traffic moves at a speed of 20 mph. At other times of the day, the arterial is not congested. There are four lanes (two lanes in each direction).

Ozone is formed by the reaction of volatile organic compounds (VOCs), an abundance of which are produced by the region, and nitrogen oxides (NO_x), a limited amount of which are produced by the region. Thus, for this region in particular, reduction of NO_x is essential to reducing ground level ozone. As shown in Figures 2 and 3, this reduction may be achieved by increasing speeds or reducing DVMT. (Figures 2 [for automobiles] and 3 [for heavy duty diesel trucks] give composite emissions factors in units of grams per vehicle mile traveled for VOC and NO_x.)

The benefits and costs of seven alternatives for reducing NO_x were considered in this scenario:

1. Support transit-oriented development (TOD).
2. Increase hours of existing transit service operation.
3. Reduce current transit fares by 50%.
4. Provide a parking subsidy for commuters who carpool.
5. Construct a reversible high-occupancy vehicle (HOV) / high-occupancy toll (HOT) lane that allows trucks.
6. Construct a reversible HOV/HOT lane that prohibits trucks.
7. Improve access management by building reverse frontage roads.

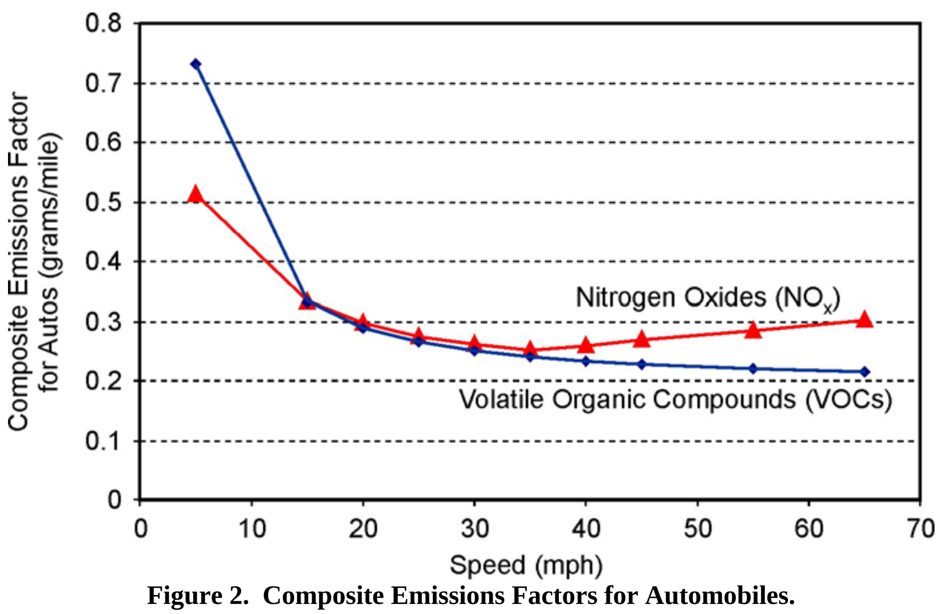

Figure 2. Composite Emissions Factors for Automobiles.
Created by executing the EPA MOBILE Emissions Model (version 6.2). All defaults were used except that all DVMT was placed on arterial and collector facilities.

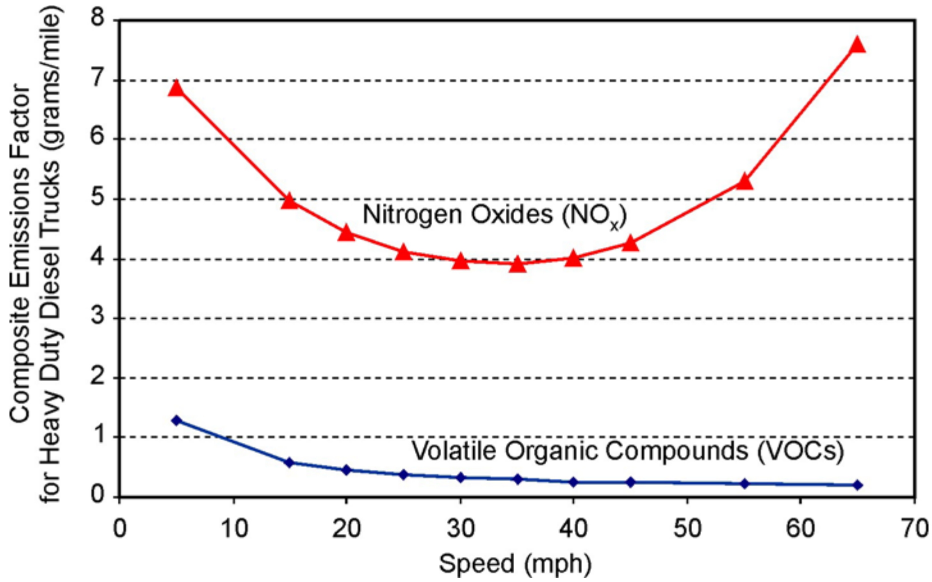

Figure 3. Composite Emissions Factors for Heavy Duty Diesel Trucks.
Created by executing the EPA MOBILE Emissions Model (version 6.2). All defaults were used except that all DVMT was placed on arterial and collector facilities.

These alternatives require different sources of funds. Alternatives 2 and 3, for example, arise from a transit operations budget, whereas Alternative 7 is based on a highway capital improvements budget. In the analysis of this case study, the impact of being able to shift funds freely among these seven alternatives was explored.

Policy Response 3: Identify Policy Initiatives to Serve Increased Demographic Market Segments

Overview

This policy response is to identify initiatives that may serve market segments that should receive increased importance in year 2035 because of changing demographics.

Case Study

To determine the impact of this policy response, a case study of the market segment of persons age 65 and older was used. Two steps were employed:

1. Quantify the expected change in the number of persons age 65 and older between 2010 and 2035.

2. Identify policy initiatives that might serve this group.

Other market segments where the identification of policy initiatives might also be productive were also identified.

Policy Response 4: Quantify the Economic Harm of General Aviation Airport Closures

Overview

This policy response is to quantify the economic loss that would result from the closure of select general aviation airports that are at risk for closure or operations restrictions.

Case Study

The impact of this policy response was determined using Virginia enplanements as a case study. These steps were used:

1. The economic benefit of Virginia enplanements was calculated.

2. The economic gain or loss that would result if enplanements increased or decreased was quantified.

The contribution of general aviation to economic impacts was also investigated.

Revision of Analysis Based on Comments from Multimodal Advisory Committee

An earlier draft of this work was presented to the VTrans2035 Multimodal Advisory Committee on October 14, 2008. Comments received at that meeting necessitated three distinct revisions to this work that were provided on the following dates: November 5 (updates to the forecasts of socioeconomic activity, highway travel demand, and transit travel demand); November 20 (an aviation forecast was added), and November 25 (Policy Response 2 was added). A revised draft was provided to the committee on December 15. An additional set of comments was received regarding the definition of *jobs to household ratio* in a conference call on January 7, 2009. As a result, these ratios were retabulated based on the methodology now provided in Appendix A.

RESULTS

Socioeconomic Forecasts for Year 2035

Modifications to PDC Compositions

To avoid double counting the five counties that are a member of two PDCs and to include one county that is not a member of any PDC, six modifications were made to the PDC composition.

1. Gloucester County, which is a member of the Hampton Roads PDC and the Middle Peninsula PDC, was included only with the Middle Peninsula PDC.

2. Franklin County, which is a member of the Roanoke Valley-Alleghany Regional Commission (Roanoke Valley-Alleghany) and West Piedmont PDC, was included only with the West Piedmont PDC.

3. Charles City County, which is a member of the Crater PDC and the Richmond Regional PDC, was included only with the Richmond Regional PDC.

4. Chesterfield County, which is a member of the Crater PDC and the Richmond Regional PDC, was included only with the Richmond Regional PDC.

5. Surry County, which is a member of the Hampton Roads PDC and the Crater PDC, was included only with the Crater PDC.

6. Nottoway County, which is not a member of any PDC, was included with the Commonwealth PDC.

For all tables throughout this report, PDC boundaries were modified as described. In addition, PDCs do not match the boundaries of metropolitan planning organizations (MPOs) perfectly. For example, a portion of Gloucester is in the Hampton Roads MPO (Ravanbakht, 2008).

Population Forecasts

Table 1 shows population forecasts to 2035 by PDC. As discussed in the "Methods" section, year 2010 forecasts were from two sources (NPA, 2008; VEC, 2008) and yielded a statewide population of between 8.01 and 8.06 million people. As also discussed, since the VEC data were available only for years 2010, 2020, and 2030 and the NPA data were available only for each year through 2030, the population forecasts for 2035 were extended from the VEC and NPA data and were 10.3 million (based on VEC data) and 10.9 million (based on NPA data). The extension of these data introduced additional uncertainty with regard to the 2035 forecasts as captured from the 95% prediction confidence interval shown Eq. 2. Thus, Table 1 also shows the low and high VEC 2035 forecasts. For example, for the Lenowisco PDC, the 95% prediction confidence interval for the VEC 2035 population forecast was 86,196 to 97,767. For the entire Commonwealth, the interval was 9.5 to 11.0 million. The low and high forecasts based on the NPA data are not provided because the 95% prediction confidence interval was much smaller than for the VEC data.

Because it is impossible to forecast a population for a state or region accurately 25 years in advance, the two sources of data provide an empirical range. Accordingly, for the Lenowisco PDC, one interpretation is that the best estimate of the 2035 population is 91,979 to 96,803 depending on the data source. Because the two right columns rely on just three data points (2010, 2020, and 2030), they may overstate the uncertainty of the population estimate; however, they are included as they provide a defensible way of estimating the range. Table 1 supports the following statements:

Table 1. Population Forecasts to 2035 by Planning District Commission

Modified PDC (PDC No.)	2010 Forecasts		Midpoint 2035 Forecasts		Low and High VEC 2035 Forecasts	
	VEC	NPA	VEC Extended[a]	NPA Extended[b]	Low[c]	High[c]
Lenowisco (1)	91,506	91,910	91,979	96,803	86,192	97,767
Cumberland Plateau (2)	114,700	112,940	118,522	116,592	101,851	135,194
Mount Rogers (3)	189,461	190,050	196,549	204,663	186,506	206,593
New River Valley (4)	175,336	170,200	196,909	199,490	183,190	210,627
Roanoke Valley-Alleghany Regional Commission (5)[d]	267,634	266,590	287,827	287,762	267,041	308,613
Central Shenandoah (6)	281,272	277,850	341,310	330,428	326,100	356,521
Northern Shenandoah Valley Regional Commission (7)[e]	225,501	224,660	324,804	308,542	304,740	344,867
Northern Virginia Regional Commission (8)	2,192,533	2,250,780	3,022,996	3,484,698	2,639,457	3,406,535
Rappahannock-Rapidan Regional Council (9)	176,584	175,960	279,603	253,073	255,472	303,734
Thomas Jefferson (10)	234,606	235,010	322,748	324,780	293,724	351,771
Virginia's Region 2000 Local Government Council (11)[f]	243,276	245,130	280,997	288,340	276,913	285,080
West Piedmont (12)	248,072	245,930	260,317	258,456	241,667	278,967
Southside (13)	85,538	85,960	84,464	94,832	75,340	93,589
Commonwealth (14)[g]	101,455	101,630	114,833	121,866	108,943	120,722
Richmond Regional (15)	994,425	1,003,920	1,319,869	1,416,551	1,222,457	1,417,281
George Washington RC (16)	345,022	355,520	595,668	638,298	561,808	629,529
Northern Neck (17)	51,721	51,910	58,378	63,265	56,862	59,893
Middle Peninsula (18)	94,630	96,350	122,282	130,942	117,210	127,355
Crater (19)[h]	180,353	170,420	220,226	190,100	199,039	241,412
Accomack-Northampton (22)	54,235	52,550	61,636	56,093	60,215	63,057
Hampton Roads (23)[i]	1,662,480	1,652,080	1,977,027	2,060,607	1,943,292	2,010,761
State Total	8,010,340	8,057,350	10,278,943	10,926,181	9,508,018	11,049,869

NPA = NPA Data Services, Inc. (2008); VEC = Virginia Employment Commission (2008).

[a] Based on VEC data for years 2010, 2020, and 2030 extended to 2035.

[b] Based on NPA data for years 2025, 2026, 2027, 2028, 2029, and 2030 extended to 2035.

[c] The low and high forecasts reflect the 95% prediction confidence interval for the VEC 2035 forecast (i.e., VEC data for years 2010, 2020, and 2030 extended to 2035). The low and high forecasts for the NPA data are not shown because the 95% prediction confidence interval was much smaller than for the VEC data. For example, for state total, the NPA 95% prediction confidence interval was 10.905 to 10.947 million, which is tighter than the VEC 95% confidence interval of 9.508 to 11.050 million shown in the last row.

[d] VEC refers to this as the Fifth District PD. This total does not include Franklin County, as it was included in the West Piedmont PDC.

[e] VEC refers to this as the Lord Fairfax PD.

[f] VEC refers to this as the Central Virginia PD.

[g] VEC refers to this as Virginia's Heartland CRCPD, and it has been called Piedmont PDC. Nottoway County was included in this PDC.

[h] This PDC does not include Charles City County or Chesterfield County as both were included in the Richmond Regional PDC.

[I] This PDC does not include Surry County (as it was included with the Crater PDC) or Gloucester County (as it was included with the Middle Peninsula PDC).

- VEC population projections suggest a 2035 state population of 10.3 million.

- Because VEC population projections are available only for 2010, 2020, and 2030, these data had to be extended using linear regression. The 95% prediction confidence interval for VEC 2035 is 9.5 (low) to 11.0 million (high).

- The 95% prediction confidence interval may imply more uncertainty than would be the case if VEC projections were available on an annual rather than decennial basis. Thus a 95% empirical confidence interval may instead be used, which is 10.3 million (from VEC) to 10.9 million (from NPA).

- The VEC and NPA forecasts differ by approximately 647,000 at the statewide level—about 6% of the VEC 2035 forecast.

Figure 4 shows forecasts from NPA (2008) and VEC (2008) that were used for VTrans2025 (Miller, 2003). For the last year for which such data were available (2025), the VTrans2025 report assumed a population between 8.5 and 9.3 million. That range deviates from this report's baseline forecast of 9.7 million by between 4% and 12%.

At the regional level, the difference in population forecasts from the two data sources was greater than at the statewide level. Using 2030 data (the last year for which forecasts from VEC and NPA are directly available), the difference in population forecasts is 491,052—about 5% of

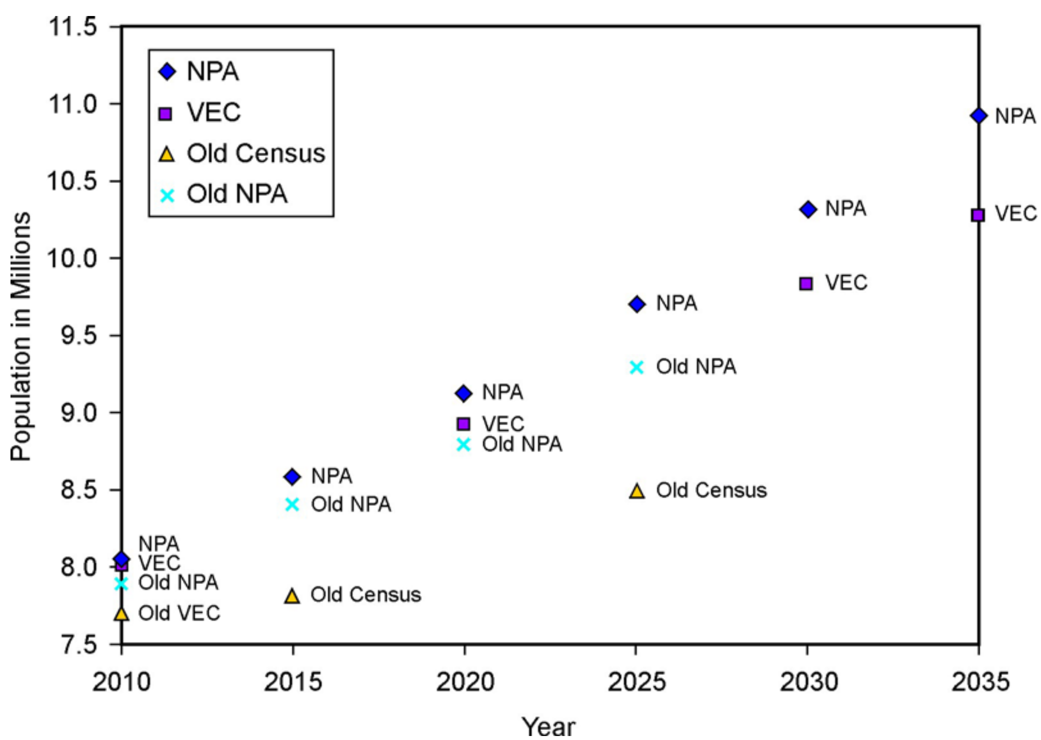

Figure 4. Population Estimates for Virginia From Different Sources.
The values for 2035 were extrapolated based on those for previous years. NPA = forecasts from NPA (2008); VEC = forecasts from VEC (2008); Old Census = census forecasts made in 1995 as reported in Miller (2003); Old NPA = forecasts from NPA made in 2003 as reported in Miller (2003).

the VEC 2030 population. If the absolute value of the difference in forecasts for each region is summed (e.g., include each regional difference as a positive value), the result is 675,510—about 7% of the VEC 2030 population.

Employment, Household Size, Household Income, and Population Density Forecasts

Forecasts for employment, household size, and household income for year 2035 are shown in Table 2. Because these are the expected forecasts assuming no unexpected changes in assumptions, these are referred to as the baseline forecasts. Another indicator of socioeconomic activity—population density—is shown in the last column of Table 2. Table 3 shows the change in these values between 2010 and 2035.

Thus between 2010 and 2035, the Commonwealth's population will grow by about one third from slightly more than 8 to 10.28 million (VEC, 2008) or 10.93 million (NPA, 2008). At the same time, the number of people per household will generally decrease in a uniform fashion

Table 2. Employment, Household Size, Household Income, and Population Density Forecasts for Year 2035[a]

Modified PDC (PDC Number)[b]	Employment (jobs)	Household Size (population per household)	Household Income (in 2000 dollars)	Population Density (people/mi^2 of land area)
Lenowisco (1)	49,430	2.36	$83,133	69.9
Cumberland Plateau (2)	55,067	2.34	$83,658	63.7
Mount Rogers (3)	127,453	2.27	$90,518	73.7
New River Valley (4)	116,894	2.47	$90,459	136.9
Roanoke Valley-Alleghany Regional Commission (5)	231,188	2.34	$118,180	176.0
Central Shenandoah (6)	222,831	2.52	$102,969	96.3
Northern Shenandoah Valley Regional Commission (7)	171,866	2.41	$104,685	188.4
Northern Virginia Regional Commission (8)	3,007,614	2.59	$207,079	2,651.1
Rappahannock-Rapidan Regional Council (9)	118,637	2.57	$140,957	129.1
Thomas Jefferson (10)	229,192	2.44	$130,013	151.3
Virginia's Region 2000 Local Government Council (11)	180,560	2.42	$109,059	135.7
West Piedmont (12)	128,640	2.31	$99,894	100.1
Southside (13)	44,780	2.45	$85,946	47.2
Commonwealth(14)	51,853	2.62	$86,816	43.4
Richmond Regional (15)	1,067,653	2.48	$139,603	663.6
George Washington RC (16)	315,979	2.71	$127,196	457.8
Northern Neck (17)	26,503	2.30	$112,294	84.8
Middle Peninsula (18)	57,503	2.43	$112,605	102.1
Crater (19)	101,577	2.59	$108,208	101.0
Accomack-Northampton (22)	29,249	2.37	$90,295	84.7
Hampton Roads (23)	1,419,270	2.63	$136,110	861.3
State of Virginia Total or Average	7,753,739	2.54	$148,948	276.0

[a] Socioeconomic data obtained from NPA Data Services, Inc. (2008) were tabulated to create 2030 totals by PDC. Data were extended to year 2035 using 2025-2030 values for each PDC using Eq. 1. Land area data were obtained from Weldon Cooper Center for Public Service (2003).
[b] PDC boundaries were modified as indicated in Table 1.

Table 3. Forecast Change in Employment, Household Size, Household Income, and Population Density from Year 2010 to Year 2035[a]

Modified PDC (PDC Number)[b]	Employment (jobs)	Household Size (population per household)	Household Income (in 2000 dollars)	Population Density (people/mi^2 of land area)
Lenowisco (1)	8,440	–0.10	$26,911	3.5
Cumberland Plateau (2)	5,797	–0.10	$27,337	2.0
Mount Rogers (3)	18,853	–0.10	$31,367	5.3
New River Valley (4)	22,754	–0.09	$27,895	20.1
Roanoke Valley-Alleghany Regional Commission (5)	37,158	–0.10	$38,598	12.9
Central Shenandoah (6)	49,601	–0.10	$31,845	15.3
Northern Shenandoah Valley Regional Commission (7)	46,356	–0.10	$30,319	51.2
Northern Virginia Regional Commission (8)	1,283,454	–0.08	$63,708	938.7
Rappahannock-Rapidan Regional Council (9)	35,437	–0.10	$45,206	39.3
Thomas Jefferson (10)	73,172	– 0.10	$41,188	41.8
Virginia's Region 2000 Local Government Council (11)	38,780	–0.11	$36,748	20.3
West Piedmont (12)	9,750	–0.09	$37,507	4.9
Southside (13)	3,420	–0.10	$28,969	4.4
Commonwealth(14)	8,163	–0.10	$26,939	7.2
Richmond Regional (15)	367,363	–0.07	$42,190	193.3
George Washington RC (16)	149,389	–0.11	$35,045	202.8
Northern Neck (17)	4,333	–0.09	$39,437	15.2
Middle Peninsula (18)	17,203	–0.09	$35,388	27.0
Crater (19)	11,627	–0.10	$35,929	10.5
Accomack-Northampton (22)	3,739	–0.10	$32,746	5.3
Hampton Roads (23)	352,480	–0.11	$44,790	170.8
State Change (2010-2035)	2,547,269	–0.08	$49,790	72.5

[a] Socioeconomic data obtained from NPA Data Services, Inc. (2008) were tabulated to create 2030 totals by PDC. Data were extended to year 2035 using 2025-2030 values for each PDC using Eq. 1. Land area data were obtained from Weldon Cooper Center for Public Service (2003).
[b] PDC boundaries were modified as indicated in Table 1.

across the state, from 2.62 in 2010 to 2.54 in 2035. Although NPA (2008) data show that the average PDC population growth rate between 2010 and 2035 is 24%, some PDCs will grow by much more than this amount, such as George Washington (80%), Northern Virginia (55%), Rappahannock-Rapidan (44%), Richmond Regional (41%), and Thomas Jefferson (38%). In terms of contribution to statewide growth, four PDCs are responsible for 2.34 million of the 2.87 million additional population in Virginia by 2035 (NPA, 2008): Northern Virginia (1.23 million), Hampton Roads and Richmond Regional (0.41 million each), and George Washington (0.28 million). These four PDCs run along the eastern portion of the Commonwealth as shown in Figure 5, and they comprise between 76% (VEC, 2008) and 81% (NPA, 2008) of the Commonwealth's population growth between 2010 and 2035.

Between 2010 and 2035, total employment will grow by almost one half, increasing from 5.21 to 7.75 million jobs. As with population, much of this growth (84%) will be concentrated in four PDCs: Northern Virginia (1.28 million), Richmond Regional (0.37 million), Hampton

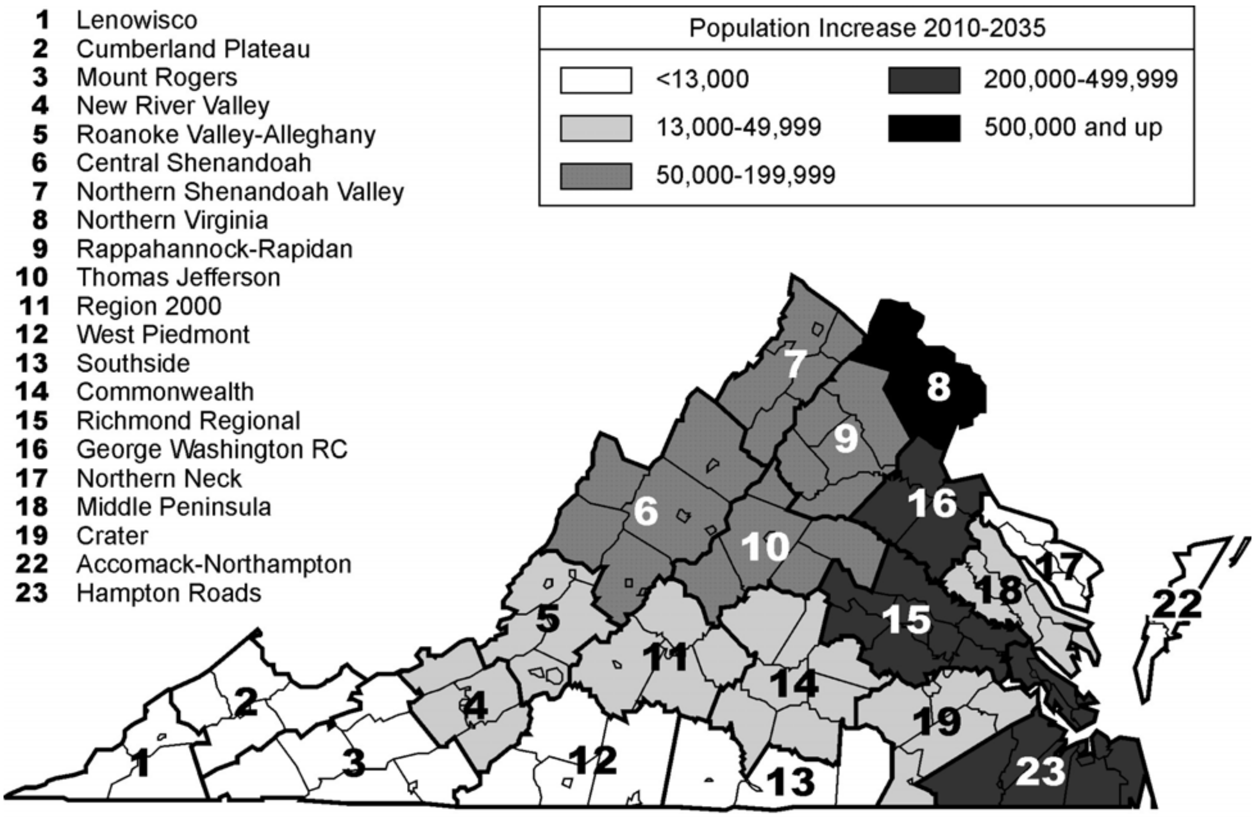

Figure 5. Change in Population Growth by PDC.
Changes were computed by taking the difference between 2010 and 2035 values based on NPA (2008) and VEC (2008) data. The Mount Rogers PDC (3) encompasses two categories, growing by between 7,088 (VEC) and 14,613 (NPA). The numbers indicate the number of the particular PDC. Virginia does not have PDCs numbered 20 or 21.

Roads (0.35 million), and George Washington (0.15 million). Individual PDCs will see employment increase on average by about one third, with above-average values for George Washington (90%), Northern Virginia (74%), Richmond Regional (52%), Thomas Jefferson (47%), and Rappahannock-Rapidan (43%).

The expected change in household income is more uniform by PDC than the changes in population and employment. Real household income (in 2000 dollars) will increase by about one half, from \$99,159 to \$148,948 in 2035. The average PDC household income will increase by about 48%: the two lowest percentage increases are for George Washington (38%) and the Northern Shenandoah Valley Regional Commission (41%), and the two highest percentage increases are for West Piedmont (60%) and Accomack-Northampton (57%). Thus generally each PDC is expected to see its real household income grow between 38% and 60%. This relative similarity in household income growth rates differs from the dissimilarity in household incomes: the smallest average household income in 2010 (\$56,222 in the Lenowisco PDC) was less than one half the largest average household income (\$143,371 in Northern Virginia). By 2035, these incomes are expected to have increased by about one half to \$83,133 and \$207,079, respectively, for the Lenowisco and Northern Virginia PDCs.

Employment to Households Ratio Forecasts

The ratio of jobs to households is a performance measure required by the *Code of Virginia* (§ 33.1-23.03). One reason for this metric is that it allows both localities and the state to offer countermeasures that can reduce congestion (California Planning Roundtable, 2008). Although this ratio has limitations (there is no ideal value and it does not account for disparities between low-income employment and high-cost housing), it can be an approximate diagnostic tool to assess the extent to which jobs and housing are in balance. To compute a jobs/household ratio, this report uses wage and salary employment, rather than total employment, and the number of households, rather than housing units. Appendix A details the advantages and disadvantages of this definition.

Figure 6 shows the ratio of wage and salary jobs to households for each PDC in 2010 and 2035. In 2010, four PDCs—Hampton Roads, Richmond Regional, Roanoke Valley-Alleghany, and Northern Virginia— had ratios above the 2010 statewide proportion of total jobs to total households. In 2035, these continue to be the only PDCs with ratios above the 2035 statewide proportion.

From 2010 to 2035, wage and salary employment is expected to increase by 45%, compared to an increase in households of about 40%. Thus, the ratio of statewide jobs to households will increase from 1.41 (in 2010) to 1.46 (in 2035). Although 10 of Virginia's 21 PDCs see a positive increase in their jobs to household ratios, the ratio for most (18) will not increase as fast as the statewide jobs/household ratio. The three exceptions are the Lenowisco,

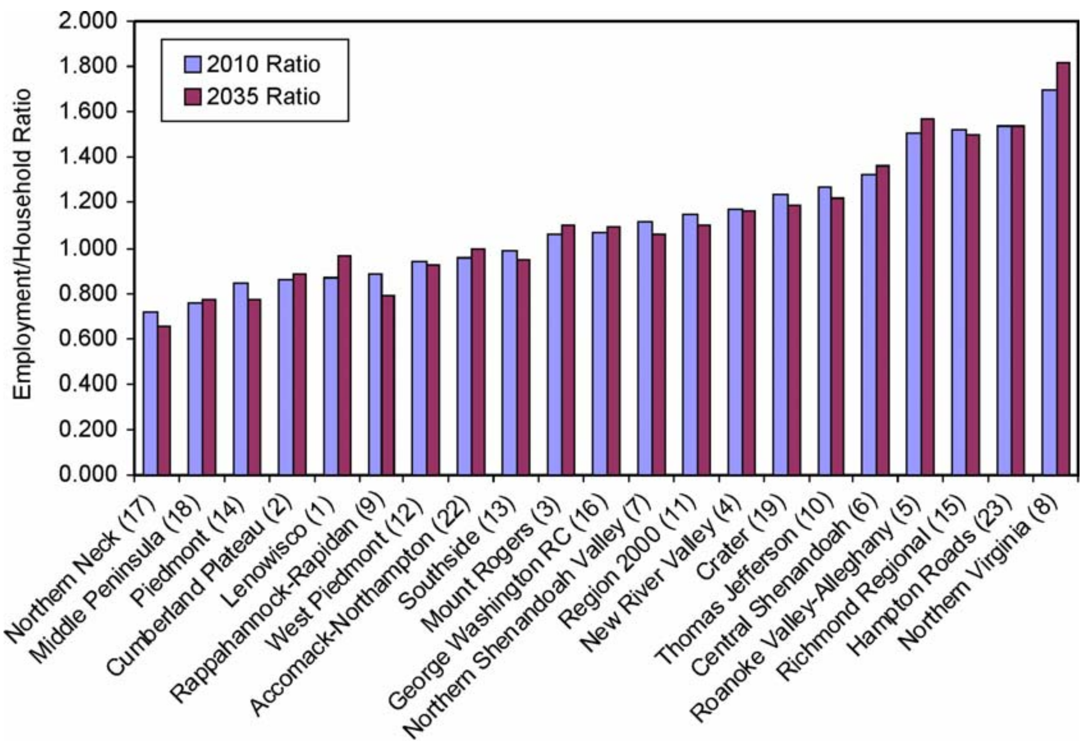

Figure 6. Wage and Salary Employment/Household Ratios for 2010 and 2035.
Data were obtained from NPA (2008).

Northern Virginia, and Roanoke Valley-Alleghany PDCs, where the individual increases in the ratio of jobs to households (0.10, 0.12, and 0.07) exceed the increase in the statewide proportion (0.05).

The implication is that the above-average jobs/household ratio in the Northern Virginia PDC (1.70, the highest in the state) is expected to increase (to 1.82). This may explain why an adjacent PDC—the George Washington Regional Council, which is the fourth largest contributor of employment and population growth between 2010 and 2035, will see its jobs to household ratio continue to remain well below the state proportion (growing from 1.07 in 2010 to 1.09 in 2035).

The ratio for the Roanoke Valley-Alleghany PDC (1.50 in 2010) will also increase further to 1.57 in 2035. Thus in 2035, this PDC's ratio will exceed the statewide proportion by a greater amount than in 2010. Ratios for Richmond Regional and Hampton Roads will remain above the statewide proportion, but this difference will shrink between 2010 and 2035. A bright spot is the Lenowisco PDC, which will see its jobs/household ratio increase from 0.87 to 0.97 over the same period.

Travel Demand Forecasts for Year 2035

Highway Forecasts

Figure 7 presents trends for statewide population, employment, fuel costs in 2007 dollars, DVMT, centerline miles, and transit trips. As may be seen, the DVMT estimates used in this report are consistent with those reported by VDOT (2007) and the Federal Highway Administration (FHWA) (2003), although the former tend to be reported on a daily basis and the latter are reported on an annual basis. For example, in the case of 2005 DVMT, reported by VDOT (2006) as 220,096,000. Multiplying this value by 365 yields close to the Virginia value of 80,337 million AVMT (FHWA, 2006).

Although a population increase is correlated with a DVMT increase for the period 1969 through 2007 ($p = 0.988$), the rate of increase is not consistent. Figure 8 shows that the ratio of population to DVMT increased from a value of about 16 (in 1969) to a value of about 19 (in 1973) and then appreciated substantially during the period 1984 through 1989, when the ratio reached a value of 27. Since that time, the ratio has increased modestly, reaching a value of 29 in 2005, as shown in Figure 8.

Figure 8 also shows that the ratio of households to DVMT followed a similar pattern, with the largest increases between 1969 and 1973 and between 1984 and 1989. (Note that the ratio of DVMT/household was divided by 2.628—the number of people per household in 2007—to make this ratio have the same order of magnitude as the ratio of DVMT/person. Thus, the difference between the two ratios is attributed to the change in the number of people per household, from a high of 3.4 in 1969 to a low of 2.6 in 2007.)

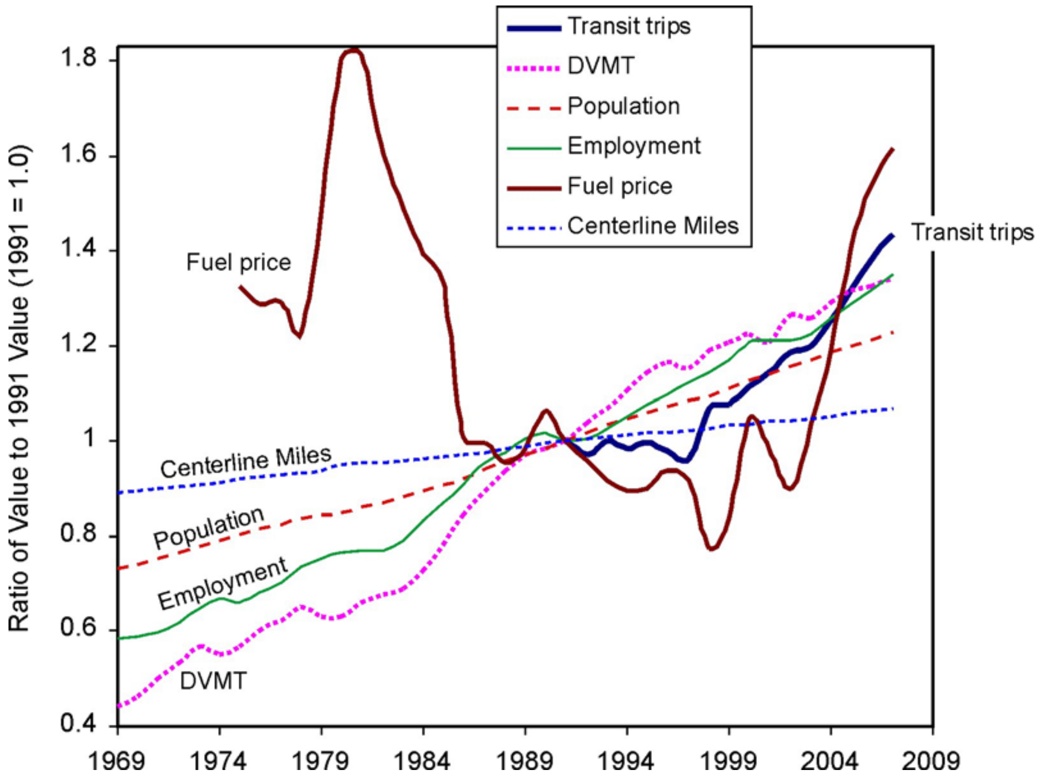

Figure 7. Statewide Population, Employment, Fuel Cost, DVMT, and Centerline Miles (1969-2007). Fuel cost is in 2007 dollars; but for year 1975, the price of unleaded gas was interpolated using the ratio of leaded to unleaded fuel costs for years 1976-1980. DVMT = daily vehicle miles of travel. *Sources:* Population and employment (NPA Data Services, Inc., 2008); fuel (Bureau of Labor Statistics [BLS], 2008; Energy Information Administration, 2008); DVMT (FHWA, 2003; Garrett, 2008; Schinkel, 2008); centerline miles (VDOT, 2009); transit trips (FTA, 2008b; Hill, 2008; McGavock, 2008; Taube, 2007).

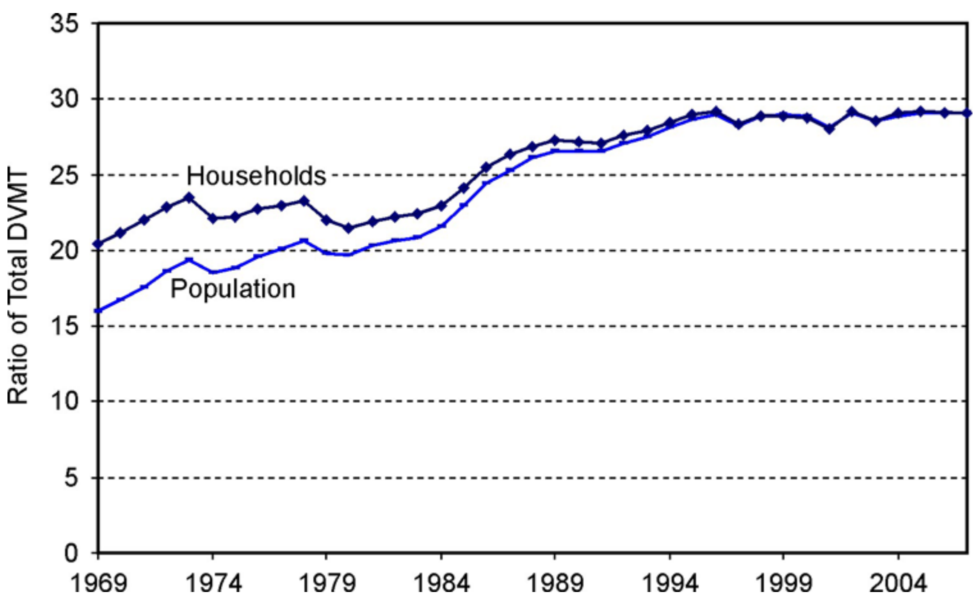

Figure 8. Ratio of Total Daily Vehicle Miles Traveled (DVMT) to Population and Number of Households. DVMT data sources were FHWA (2003) for 1969-1983; Garrett (2008) for 1984-2005; and Schinkel (2008) for 2006-2007; population and households data were obtained from NPA (2008). Ratio of DVMT/households was divided by 2.628 (the number of people per household in 2007) to place both ratios on the same axis.

Figure 9 shows that the ratio of statewide DVMT per lane-mile has steadily increased since 1980, which was to be expected given that DVMT has grown substantially faster than miles of highway construction. For the period 1980 through 2006, the DVMT per lane-mile almost doubled, from 773 to 1,416. This increase in traffic density was not uniform throughout the state. For example, although the average daily traffic (ADT) for Route 29 between Danville and the North Carolina state line increased by an amount comparable to the statewide ratio of DVMT per lane-mile the ADT for an urbanized section of I-64 increased by a factor of 4.5 over the same period.

Table 4 shows four DVMT forecasts: DVMT growth at the same annual rate as in the period 1982 through 2007 (high DVMT growth); DVMT growth as a function of population using estimates based on NPA (2008); DVMT growth as a function of population using estimates based on VEC (2008); and DVMT growth based on rates that are expected to be lower than previous rates (low DVMT growth) (Liu et al., 2007).

Because DVMT growth is not expected to be even across the Commonwealth, the forecasts of statewide DVMT provided in Table 4 were distributed to each PDC area in a manner proportionate to the 2035 population as shown in Eq. 6.

$$\mathrm{DVMT}_{\mathrm{PDC}} = \left(\frac{\text{PDC population in 2035}}{\text{State population in 2035}} \right) \text{State VMT in Table 4} \qquad \text{[Eq. 6]}$$

For example, the VEC data suggest the Lenowisco PDC will have a 2035 population of 91,979 (see Table 1), which is 0.89% of the statewide 2035 population. Thus, if a statewide DVMT of 321.2 million (see Table 4) is assumed, the DVMT for the Lenowisco PDC in 2035 is forecast to be 0.89% of 321.2 million, or 2.9 million, DVMT, as shown in Table 5.

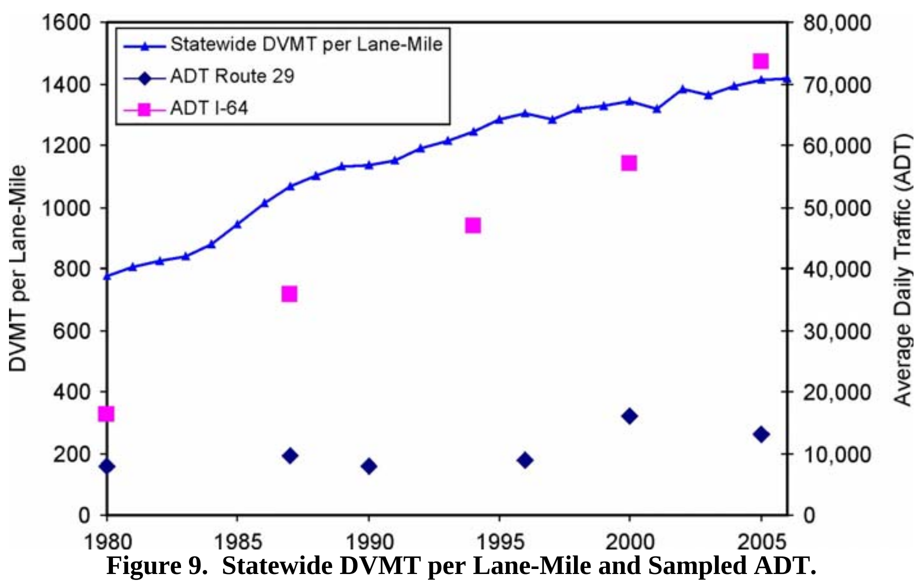

Figure 9. Statewide DVMT per Lane-Mile and Sampled ADT.
Lane-mile data were extracted from FHWA (2008); e.g., see FHWA (2002) for 1980-1995 lane-miles and FHWA (2007) for 2006 lane-miles. Statewide DVMT were extracted from FHWA (2003), Garrett (2008), and Schinkel (2008). Population and households data were obtained from NPA (2008). ADT for Route 29 reflects the ADT immediately north of the North Carolina state line as obtained from VDOT (1969-2007). ADT for I-64 reflects the ADT between Route 17 and I-264 as obtained from VDOT (1969-2007).

Table 4. Possible Growth in Daily Vehicle Miles Traveled (DVMT) Between 2010 and 2035

Scenario	Assumption Regarding DVMT Growth Between 2010 and 2035	DVMT
High DVMT Growth	Annual growth rate will be the same as that for 1982-2007 (2.77%)	483.6 million
DVMT Based on NPA (2008) Population	Growth will depend on population (Eq. 3) with a 2035 population of 10.926 million	345.4 million
DVMT Based on VEC (2008) Population	Growth will depend on population (Eq. 3) with a 2035 population of 10.279 million	321.2 million
Low DVMT Growth	Annual growth rates will be 1.74% (through 2010), 1.58% (2011-2020), and 1.31% (2021-2035) (Liu et al., 2007)	336.7 million

NPA = NPA Data Services, Inc.; VEC = Virginia Employment Commission.

Table 5. Daily Vehicle Miles Traveled (DVMT) by Planning District Commission (PDC) (in Millions)

Modified PDC[a] (PDC Number)	High DVMT Growth[b]	DVMT Based on NPA Population[c]	DVMT Based on VEC Population[d]	Low DVMT Growth[e]
Lenowisco (1)	4.3	3.1	2.9	3.0
Cumberland Plateau (2)	5.2	3.7	3.7	3.6
Mount Rogers (3)	9.1	6.5	6.1	6.3
New River Valley (4)	8.8	6.3	6.2	6.1
Roanoke Valley-Alleghany Regional Commission (5)	12.7	9.1	9.0	8.9
Central Shenandoah (6)	14.6	10.4	10.7	10.2
Northern Shenandoah Valley Regional Commission (7)	13.7	9.8	10.1	9.5
Northern Virginia Regional Commission (8)	154.2	110.1	94.4	107.4
Rappahannock-Rapidan Regional Council (9)	11.2	8.0	8.7	7.8
Thomas Jefferson (10)	14.4	10.3	10.1	10.0
Virginia's Region 2000 Local Government Council (11)	12.8	9.1	8.8	8.9
West Piedmont (12)	11.4	8.2	8.1	8.0
Southside (13)	4.2	3.0	2.6	2.9
Commonwealth(14)	5.4	3.9	3.6	3.8
Richmond Regional (15)	62.7	44.8	41.2	43.7
George Washington RC (16)	28.3	20.2	18.6	19.7
Northern Neck (17)	2.8	2.0	1.8	1.9
Middle Peninsula (18)	5.8	4.1	3.8	4.0
Crater (19)	8.4	6.0	6.9	5.9
Accomack-Northampton (22)	2.5	1.8	1.9	1.7
Hampton Roads (23)	91.2	65.1	61.8	63.5
State Total	483.6	345.4	321.2	336.7

NPA = NPA Data Services, Inc.; VEC = Virginia Employment Commission.
[a]PDC boundaries were modified as indicated in Table 1.
[b] Assumes statewide DVMT growth rate of 2.77% per year (same as that for 1982-2007) (see Table 4).
[c] Assumes statewide DVMT will depend on 2035 NPA population of 10.926 million as per Eq. 3 (see Table 4).
[d] Assumes statewide DVMT will depend on 2035 VEC population of 10.279 million as per Eq. 3 (see Table 4). Eq. 6 was applied using forecasts based on VEC (2008) for this particular set of forecasts.
[e] Assumes statewide DVMT annual growth rates of 1.74% through 2010, 1.58% for 2011-2020, and 1.31% for 2021-2035 (see Table 4).

There is additional uncertainty with regard to the values in Table 5 when DVMT is attributed to a specific PDC: for some PDCs, it may be the case that the DVMT attributed to that PDC should be attributed to an adjacent PDC. For example, some of the DVMT in the

Lenowisco PDC may be driven by the larger population in the Cumberland Plateau PDC. Appendix B, however, suggests that this uncertainty is relatively small. For example, the four PDCs of George Washington, Hampton Roads, Northern Virginia, and Richmond Regional had 59.8% of the statewide measured DVMT and 64.2% of the statewide population. Yet these areas also have a larger transit component than other locations in the state (T. Biesiadny, personal communication, October 14, 2008). When both DVMT and transit travel are considered, these four PDCs had 60.2% of the state's combined DVMT and passenger travel as shown in Appendix B, which is closer to their 64.2% share of the state's population.

Transit Forecasts

Figure 10 shows the growth in statewide unlinked transit trips based on data extracted from the National Transit Database (FTA, 2008b, Hill, 2008) and the Northern Virginia Transportation Commission (McGavock, 2008; Taube, 2007). From 1991 through 2007, statewide unlinked transit trips increased from 134 to 192 million, yielding an average annual percentage increase of 2.27%. During this time period, fuel costs decreased from 1991 through 1998 and then steadily increased through 2007, except for a drop between 2000 and 2002. The largest increase in transit trips (statewide, on bus systems other than the Washington

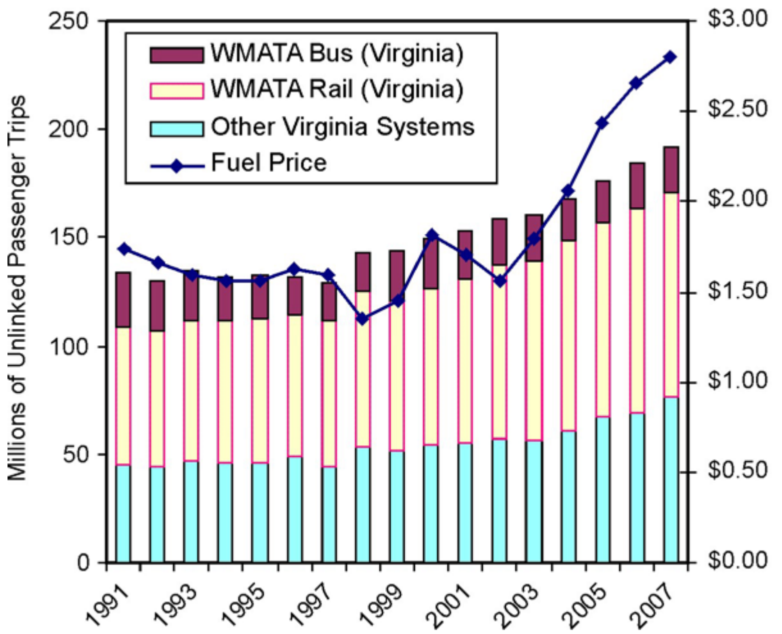

Figure 10. Change in Transit Ridership and Fuel Cost, 1991-2007.
Year 1999-2007 data were extracted from Hill (2008) and include all Virginia transit systems. Because DRPT data were not available for 1991-1998, these data were extracted from FTA (2008b). The FTA data include systems in Charlottesville, Danville, Fairfax City, Fairfax County, Fredericksburg, Hampton Roads, Harrisonburg, Loudoun County, Lynchburg, Petersburg, Richmond, Williamsburg, Woodbridge, and the Washington Area Metropolitan Transit Authority (WMATA). Two adjustments were made to the FTA data in order to report statewide estimates for 1991-1998. First, for 1999-2007, DRPT data showed that WMATA bus and rail service in Virginia accounted for 14.05% and 33.63%, respectively, of total WMATA bus service. As FTA reports only total WMATA bus and rail service for 1991-1998, these percentages were used to estimate the portion of WMATA bus and rail service in Virginia for that period. Second, for 1999-2007, the FTA data underreport ridership compared to DRPT data by an average of 2.36% (attributable in part to smaller systems [e.g., Town of Chincoteague] not being included); thus FTA data were adjusted by this percentage for 1991-1999. Fuel data were extracted from BLS (2008) and Energy Information Administration (2008).

Metropolitan Area Transit Authority [WMATA] [non-WMATA bus systems] and WMATA rail) occurred after 1998 when fuel costs rose. Fuel costs varied considerably over this period.

There is some uncertainty regarding the data prior to 1997 because the portion of WMATA bus service attributable to Northern Virginia, as opposed to Washington, D.C., or Maryland, is not directly reported. Two datasets—those from the Northern Virginia Transportation Commission (McGavock, 2008; Taube, 2007) and those from Hill (2008)—were used to estimate these portions based on data after 1997 when such trips were reported. For WMATA bus service, the portions are similar for each dataset: data from 1999 through 2006 (FTA, 2008b; Hill, 2008) suggested that Virginia accounted for 14.05% of WMATA bus trips, whereas data from 1997 through 2006 (FTA, 2008b; McGavock, 2008; Taube, 2007) suggested that Virginia accounted for 14.34% of WMATA bus trips. Use of the Northern Virginia Transportation Commission portions indicates that there was a total of 134 million trips in 1991, meaning the annual increase in transit trips to 2007 was 2.19% (similar to the 2.27% noted previously).

Although the 1991 through 2007 data therefore suggest annual increases of 2.19% to 2.27%, Figure 10 shows that a different average annual growth rate may be obtained if a different time period is selected. For example, the period 1991 through 1997 yields a negative annual growth rate (–0.65%) whereas the period 1997 through 2007 shows a high positive annual growth rate (4.07%). Individual systems may see greater or lesser growth: non-WMATA transit trips in Northern Virginia grew at an average annual rate of 8.6% from 2001 through 2006 (Taube, 2007). Based on these annual growth rates for 1991 through 2007, Figure 11 shows four different forecasts of transit growth for 2035 relative to the 192 million trips in 2007.

If the growth for 1997 through 2007 were sustained until 2035, transit trips could be as high as 587 million; if transit growth dropped comparable to 1991 through 1997, growth could be as low as 160 million trips. Without any change in revenue policies, the likelihood of either

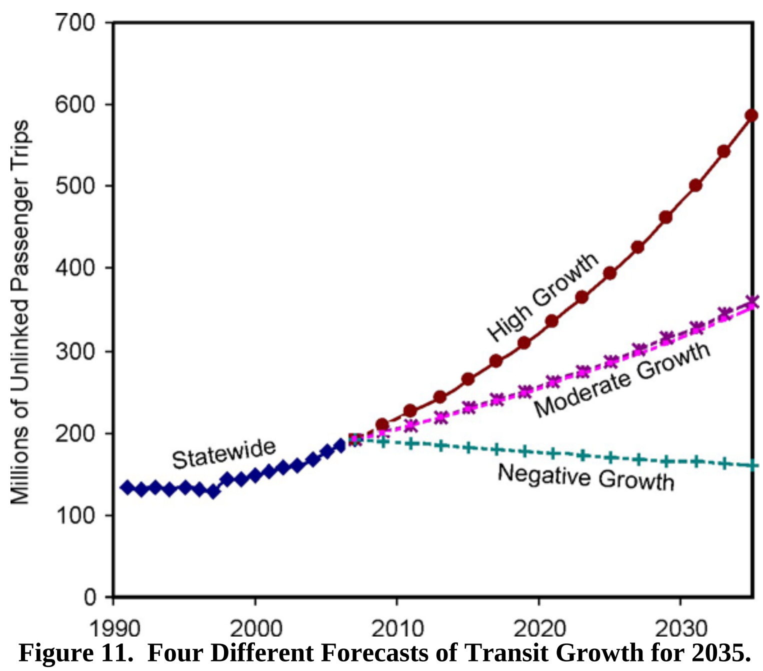

Figure 11. Four Different Forecasts of Transit Growth for 2035.

scenario occurring over a 25-year period appears less than that suggested by the more moderate alternative of assuming that transit growth will be comparable to that from 1991 through 2007, a period that saw both an increase and a decrease. A middle 2035 forecast of 352 to 360 million is shown in Table 6. However, as discussed in the "Discussion" section (i.e., "Limitations of the Analysis"), a change in costs for other modes of travel, such as tolls for highway facilities, should affect this transit forecast.

Table 6. Possible Growth in Annual Unlinked Transit Trips Between 2010 and 2035

Scenario	Assumption Regarding Transit Growth Between 2010 and 2035	Trips
High Transit Growth	Statewide transit trips will grow at an annual increase of 4.07% (the rate of increase for 1997-2007).	586.6 million
Moderate Transit Growth	Statewide transit trips will grow at an annual increase of 2.27% (the rate of increase for 1991-2007 assuming that Virginia accounted for 14.05% of the WMATA bus trips in 1991).	360.3 million
Moderate Transit Growth	Statewide transit trips will grow at an annual increase of 2.19% (the rate of increase for 1991-2007 assuming that Virginia accounted for 14.34% of WMATA bus trips in 1991).	352.1 million
Negative Transit Growth	Statewide transit trips will decrease by 0.65% per year (the rate of decrease for 1991-1997).	159.9 million

WMATA = Washington Metropolitan Area Transit Authority.

Aviation Forecasts

Historical Trends in Enplanements

Virginia has 67 airports: 9 provide commercial service (defined as either providing regularly scheduled service or having at least 10,000 enplanements per year), 7 serve to reduce congestion at the 9 commercial service airports, and 50 provide either general aviation or local

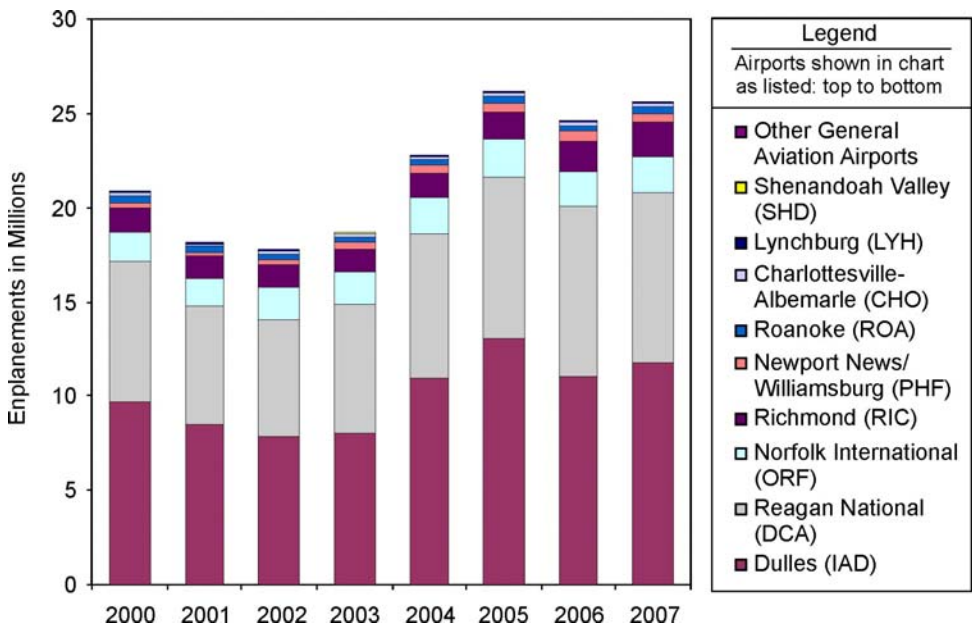

Figure 12. Virginia Enplanements, 2000-2007.
Data were extracted from FAA (2008b).

service (DOAV, 2006a). Figure 12 shows that the four largest airports (Dulles International Airport [Dulles], Ronald Reagan Washington National Airport [Reagan National], Norfolk International Airport, and Richmond International Airport) accounted for about 96% of Virginia's total enplanements from 2000 through 2007 (25.6 million passengers in 2007). As discussed previously, an enplanement is a boarding passenger; for example, in 2007, Richmond International showed 1.82 million enplaned passengers and 1.81 million deplaned passengers (Capital Region Airport Commission, 2008). Virginia has a large number of smaller airports, such as the Louisa County Airport / Freeman Field, which had 22 enplanements in 2007 (FAA, 2008b).

From 2000 through 2007, annual enplanements statewide grew at an average rate of 2.97%, which was comparable to the rate of growth at Virginia's three largest airports (2.91% at Dulles, 2.67% at Reagan National, and 3.00% at Norfolk International) and below the rate of growth at Richmond International (almost 4.46%). At Virginia's smaller airports, annual rates of growth varied substantially over this period: for example, for Newport News–Williamsburg International Airport growth increased at an average annual rate of 12.32%, whereas for Shenandoah Valley Regional Airport, growth *decreased* at an annual rate of –18.82%. Table 7 shows enplanements by year and selected airport for years 2000 through 2007.

Forecast of Baseline Growth in Enplanements

Application of Eq. 4 or Eq. 5 for each row in Table 7 suggests that Virginia enplanements will grow from 25.61 million (in 2007) to 56.66 million (in 2035)—an increase of 121%. This increase is comparable to, but moderately lower than, a previous forecast for the period 2000 to 2020, discussed here, that might have suggested a 159% increase in enplanements between 2007 and 2035.

The 159% increase was derived from a forecast by SH&E et al. (2003). They estimated 21.58 million commercial enplanements and 1.59 million general aviation *operations* in 2000 compared with projections of 43.88 million commercial enplanements and 2.37 million general aviation operations in 2020 (SH&E et al., 2003). If one assumes that each general aviation operation reflects 1.75 general aviation enplanements, the total projected enplanements from 2000 to 2020 increase from 24.37 to 48.04 million, which is an average annual percent increase of 3.45%. If this 3.45% increase were applied to the period 2007 to 2035, Virginia enplanements would increase 159% in 2035 relative to 2007. (Changing the assumed relationship of general aviation operations to enplanements from 1.75 affects this forecast: if, for example, one assumes 3.0 general aviation enplanements per operation, the forecast changes from 159% to 152%.)

External Influences Affecting Travel Demand Forecasts

Travel demand is affected by a wide variety of factors, such as economic growth, commercial and residential development patterns, the cost of travel, and external funding. The influence of selected factors on each mode—highway DVMT, transit trips, and aviation enplanements—were considered separately.

Table 7. Annual Enplanements at Virginia Airports, 2000-2007[a]

Airport	2000	2001	2002	2004	2005	2006	2007	Average Annual % Growth
Dulles International (IAD)	9,643,275	8,484,112	7,848,911	10,961,614	13,032,502	11,045,217	11,789,441	2.91%
Ronald Reagan Washington National (DCA)	7,517,811	6,267,395	6,172,065	7,661,532	8,623,907	8,973,410	9,038,174	2.67%
Norfolk International (ORF)	1,518,552	1,478,687	1,731,105	1,895,472	1,953,003	1,862,325	1,867,307	3.00%
Richmond International (RIC)	1,330,487	1,187,681	1,168,023	1,251,406	1,452,066	1,644,419	1,805,992	4.46%
Newport News–Williamsburg International (PHF)	227,635	206,750	293,181	451,113	514,361	513,367	513,381	12.32%
Roanoke Regional (ROA)	364,202	304,265	298,606	306,896	326,202	326,214	348,634	–0.62%
Charlottesville Albemarle (CHO)	165,938	155,863	173,543	185,531	198,133	185,891	187,078	1.73%
Lynchburg Regional (LYH)	82,459	65,120	52,699	61,441	65,895	60,737	55,785	–5.43%
Shenandoah Valley Regional (SHD)	21,113	19,092	6,633	7,709	5,307	5,375	4,907	–18.82%
Other General Aviation Airports[b]	1,697	247	1,512	984	569	1,663	1,251	–4.26%
Total	20,873,169	18,169,212	17,746,278	22,783,698	26,171,945	24,618,618	25,611,950	2.97%

[a] Data were extracted from FAA (2008b). Year 2003 data are not shown because of space limitations; in 2003 there was a total of 18,652,921 enplanements (FAA, 2008b).
[b] Represents all other Virginia airports as reported by the FAA (2008b). Such airports consistently had a smaller number of enplanements than those shown elsewhere in the table. The exact airports with reported enplanements in this category vary by year. For example, Blue Ridge Airport (MTV), which had 3 enplanements in 2007, is shown in 2000 and 2002-2007 data but not in 2001 data.

External Influences Affecting Highway Forecasts

The impact of changes in fuel costs, income, and density was calculated for each of the four DVMT scenarios shown in Table 4 (High DVMT Growth, DVMT Based on NPA [2008] Population, DVMT Based on VEC [2008] Population, and Low DVMT Growth) as follows:

- *Change in fuel costs*. The impact of fuel costs on DVMT was evaluated by using Eq. 7 with a low fuel cost of $1/gallon and a high fuel cost of $10/gallon. The base price of fuel was $2.80/gallon (the fuel cost in 2007). Elasticities of –0.19 and – 0.32 were used in Eq. 7.

$$\text{New DVMT} = \text{Base DVMT}\left[\text{elasticity}\,\frac{\text{New Fuel Cost} - \text{Base Fuel Cost}}{\text{Base Fuel Cost}} + 1\right] \qquad \text{[Eq. 7]}$$

- *Change in income growth.* A comparable method (see Eq. 8) was used for income growth. The base figure was a projected growth in household income of 50.21% between 2010 and 2035 (see Table 3). The low income growth figure was chosen as 0.0021% growth in income and the high income growth as an increase of 100.21%. Elasticities of 0.10 and 0.65 were considered.

$$\text{New DVMT} = \text{Base DVMT}\left[\text{elasticity}\,\frac{\text{New Income Growth Rate} - \text{Base Income Growth Rate}}{\text{Base Income Growth Rate}} + 1\right] \qquad \text{[Eq. 8]}$$

- *Increased density*. The impact of increasing density was considered by placing all new inhabitants between 2010 and 2035 in what is currently the most densely populated PDC; the base figure was the 2035 projections as shown in Table 1. Elasticities between –0.05 and –0.29 were considered. Because the increased density would affect only a portion of the population, Eq. 7 was modified as shown in Eq. 9.

$$\begin{aligned}\text{New DVMT} = {} & \text{Base DVMT}(\text{Percent DVMT Unaffected by Increased Density} \\ & + \text{Percent DVMT Affected by Increased Density}\left[\text{Elasticity}\,\frac{\text{New Density} - \text{Base Density}}{\text{Base Density}} + 1\right]\end{aligned} \qquad \text{[Eq. 9]}$$

Table 8 shows the results of varying fuel cost, income, and density for each DVMT scenario. For example, consider the low DVMT estimate of 336.7 million. The next row shows that a drop in fuel costs to $1/gal would increase this DVMT to 377.8 million or 406.0 million, depending on which elasticity is assumed in Eq. 7. Still assuming low DVMT growth, the largest difference between any two rows is 495 million DVMT as shown at the bottom of Table 8. This 495 is the difference between the largest value in the low DVMT growth column (554.7 for high income growth presuming a high positive elasticity as per Eq. 8) and the smallest value in the same column (59.6 for a high fuel cost presuming a more negative elasticity as per Eq. 7).

Table 8. Summary Sources of Variation and Uncertainty on Statewide 2035 Daily Vehicle Miles Traveled (DVMT)

Factor	Elasticity	High DVMT Growth[a]	DVMT Based on NPA Population[b]	DVMT Based on VEC Population[c]	Low DVMT Growth[d]	Range (Highest – Lowest)
Base Case (i.e., values noted in Table 4)	N/A	483.6	345.4	321.2	336.7	162
Low Fuel Cost[e]	Low (–0.19)	542.6	387.5	360.4	377.8	182
	High (–0.32)	583.1	416.4	387.2	406.0	196
High Fuel Cost[e]	Low (–0.19)	247.3	176.6	164.2	172.2	83
	High (–0.32)	85.7	61.2	56.9	59.6	29
Low Income Growth[f]	Low (0.10)	435.4	311.0	289.2	303.2	146
	High (0.65)	170.6	121.8	113.3	118.8	57
High Income Growth[f]	Low (0.10)	531.7	379.8	353.1	370.3	179
	High (0.65)	796.6	568.9	529.0	554.7	268
Increased Density[g]	Low (–0.05)	478.3	341.6	317.6	333.0	161
	High (–0.29)	452.7	323.3	300.7	315.3	152
Range (Highest – Lowest)		711	508	472	495	

[a] Assumes statewide DVMT growth rate of 2.77% per year (same as for 1982-2007).
[b] Assumes statewide DVMT will depend on 2035 NPA population of 10.926 million as per Eq. 3.
[c] Presumes statewide DVMT will depend on 2035 VEC population of 10.279 million as per Eq. 3.
[d] Presumes statewide annual growth rates of 1.74% through 2010, 1.58% for 2011-2020, and 1.31% for 2021-2035.
[e] Low and high fuel costs are $1/gal and $10/gal unleaded in 2007 dollars. Base case is $2.80/gal (Eq. 7).
[f] Low and high income growths are increases of 0.0021% and 100.21% in household income in real dollars between 2010 and 2035. Base case is an increase of 50.21% between 2010 and 2035 (Eq. 8).
[g] Upper bound of increased density was considered as follows: 2.87 million new inhabitants will come to Virginia between 2010 and 2035. All 2.87 million were placed in the most densely populated portion of the Commonwealth (Northern Virginia), which increases the density of that PDC from 2,651 to 3,895 people/mi^2. Given that Northern Virginia's 2035 population under this scenario thus represents 46.86% of the 2035 population, Eq. 9 was used to reduce 46.86% of the base case DVMT shown in the first row of Table 8. These calculations yield 478.3 million DVMT:

$$\text{New DVMT} = 483.6(53.14\% + 46.86\%\left[-0.05\frac{3{,}895\,\text{people/mi}^2 - 2{,}651\,\text{people/mi}^2}{2{,}651\,\text{people/mi}^2} + 1\right] = 478.3\,.$$

It is evident that the four ranges shown in the last row of Table 8 (e.g., 711, 508, 472, and 495 million DVMT) are generally much larger than the ranges shown in the last column (e.g., 162, 182, 196, and so on). The practical implication is that the variation by assumption about the DVMT growth rate is not as large as the variation in DVMT resulting from changes in fuel cost, household income, and elasticity.

Figure 13 depicts this variation. The length of each vertical bar is proportionate to the impact of elasticity. For example, under the scenario of high DVMT growth and the factor of high fuel cost (see the lower left corner of Figure 13), assumptions regarding elasticity cause a sizeable amount of variation from roughly 86 to 247 million DVMT. A similarly large range of 532 to 797 million DVMT is evident for the same high DVMT growth scenario but presuming high income growth (see the upper left corner of Figure 13). Despite this high range in elasticity, the disparate impacts of high income growth and high fuel costs are evident.

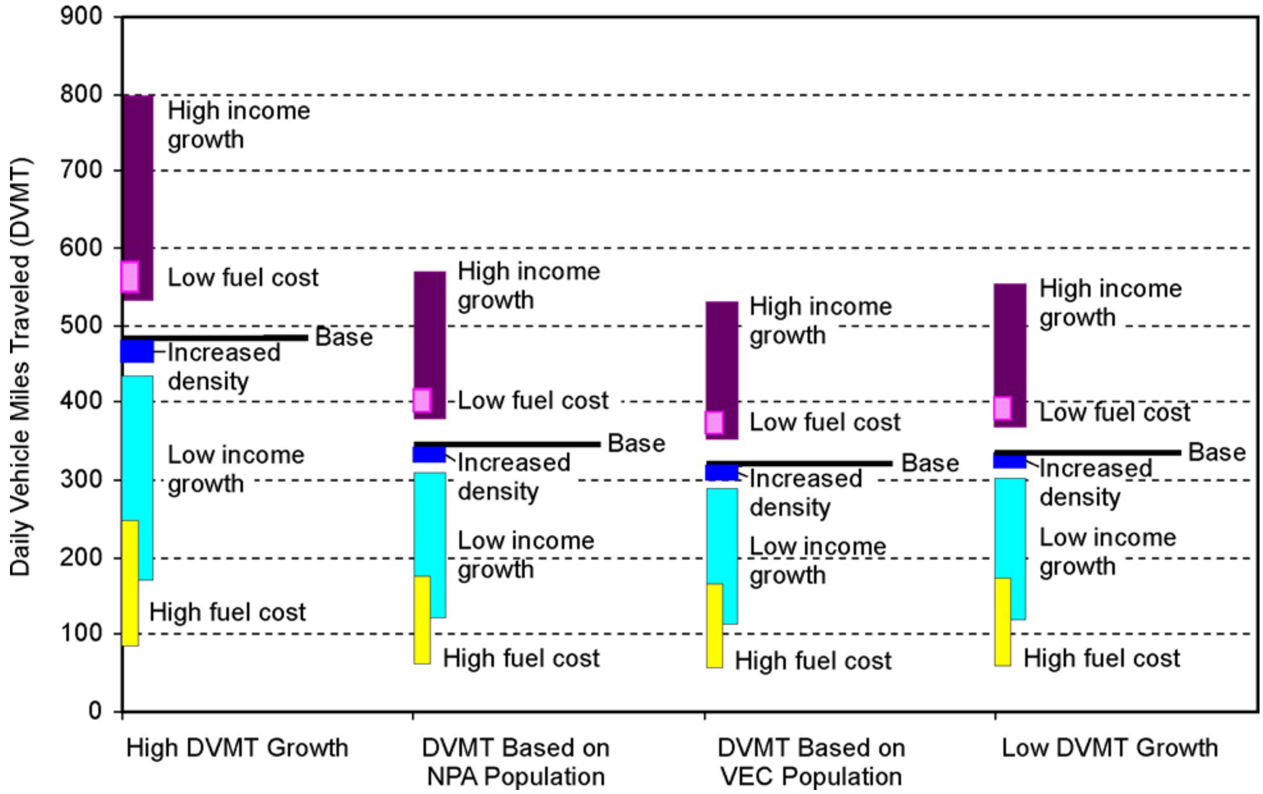

Figure 13. Variation in Daily Vehicle Miles Traveled (DVMT) As Function of Annual Growth Rate, Fuel Cost, Household Income, Density, and Related Elasticities.

External Influences Affecting Transit Forecasts

Table 5 suggested a best estimate transit forecast of 360 million trips in 2035 but also showed that a range of trips, between 160 million and 587 million, was possible based on extrapolation of previous growth rates. Transit trips are affected by other factors, two of which are noted here: external funding and fuel costs.

Figure 14 shows that the total state, federal, and local transit funds for Virginia's transit systems have grown since 1991, although it was not the case that they increased every year. For example, the sum of local, state, and federal funds for non-WMATA transit systems decreased from 1993 to 1994 and again from 2002 to 2003. Such funds were relatively flat from 1999 to 2000 but then jumped considerably in 2001. Thus although an average increase is noted, there was uncertainty in funding from year to year.

As was the case with ridership, the largest portion of funds was attributed to the WMATA system. The literature provides only a total cost figure for WMATA; thus an estimated 26.7% of these funds were attributed to the Virginia portion based on previous work (FTA, 2008b; Hill, 2008; Taube, 2007). The WMATA system shows that the proportion of federal funds decreased from 1991 to 2006, although total funds increased slightly. Figure 15 also emphasizes the variability in funding from year to year.

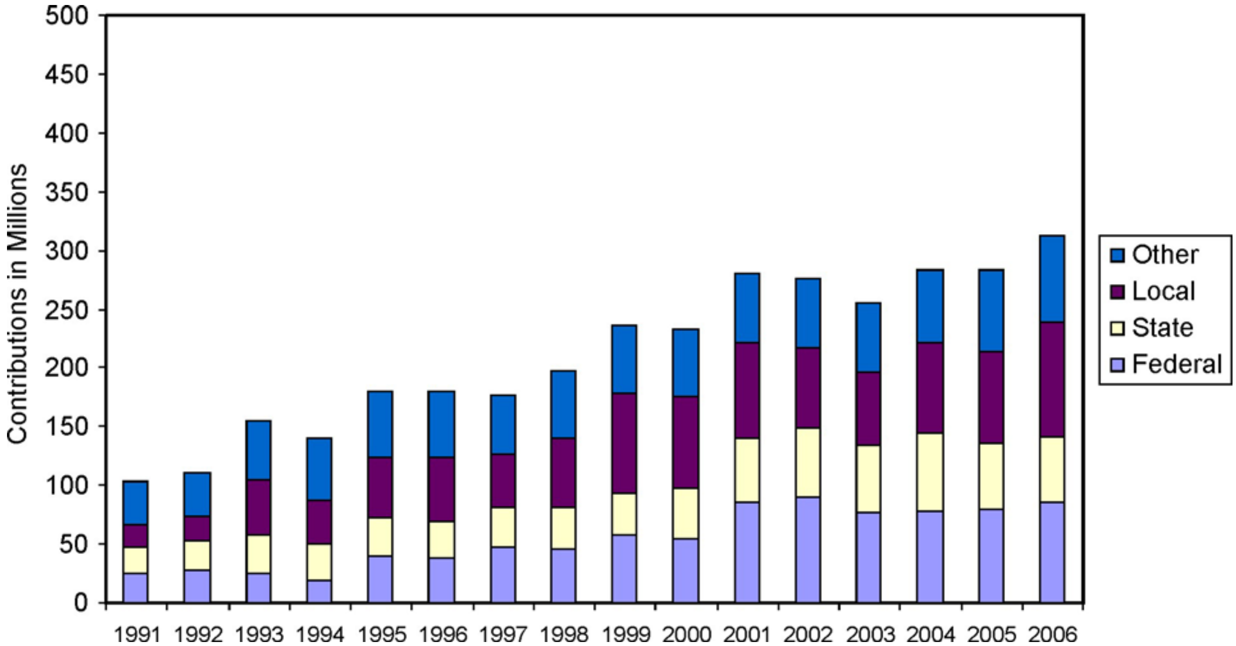

Figure 14. Total Federal, State, and Local Capital and Operating Funds for Virginia Transit Systems. Does not include WMATA. Cost data were extracted from FTA (2008a) and converted to 2007 dollars (BLS, 2008).

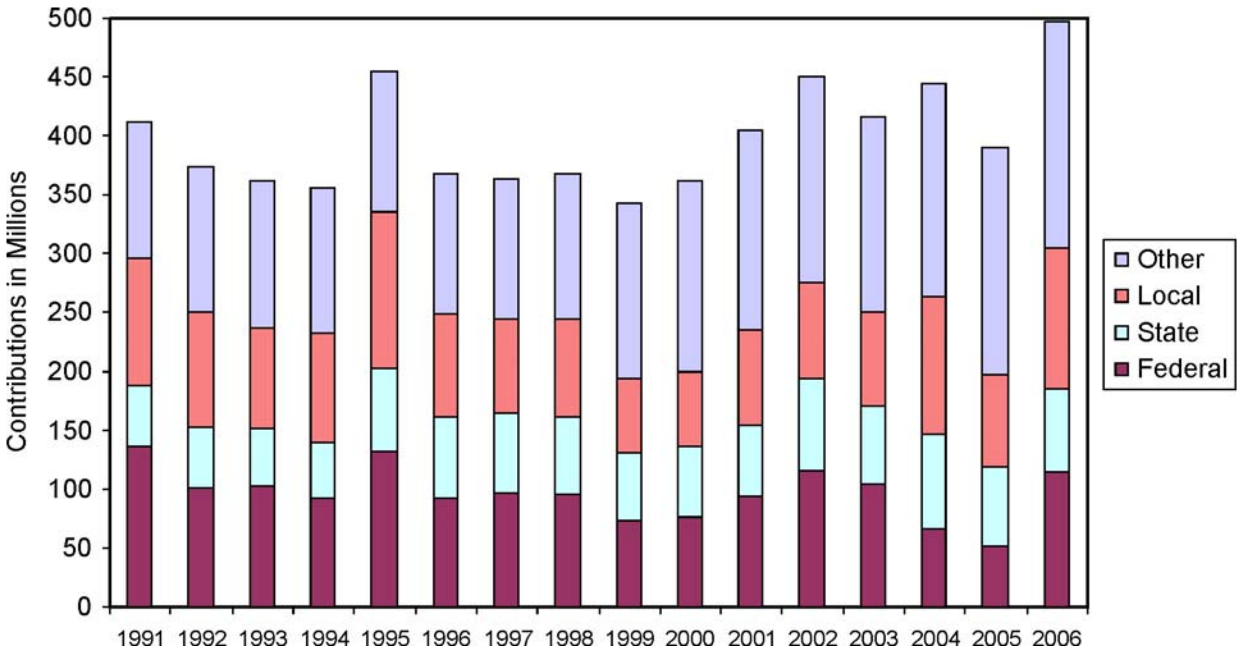

Figure 15. Total Federal, State, and Local Capital and Operating Funds for WMATA. Cost data were extracted from FTA (2008a) and converted to 2007 dollars (BLS, 2008). This figure assumes that 26.7% of WMATA's funds originate in Virginia based on Hill (2008).

To some extent, reduced DVMT may be offset by increased transit use. For example, the literature (Litman, 2007) suggests that the cross-elasticity of transit with respect to fuel costs may vary as a function of the quality of the transit service and trip purpose, with an average long-run elasticity of 0.12 being suggested (meaning that a 1% increase in fuel costs may increase transit ridership by 0.12%). Given a fuel cost of $2.80 in 2007 (also in 2007 dollars) and moderate transit growth, Figure 16 shows that a drop in fuel costs to $1/gal would decrease transit use to 332 million unlinked passenger trips whereas an increase in fuel costs to $10/gal would increase transit use to 471 million such trips.

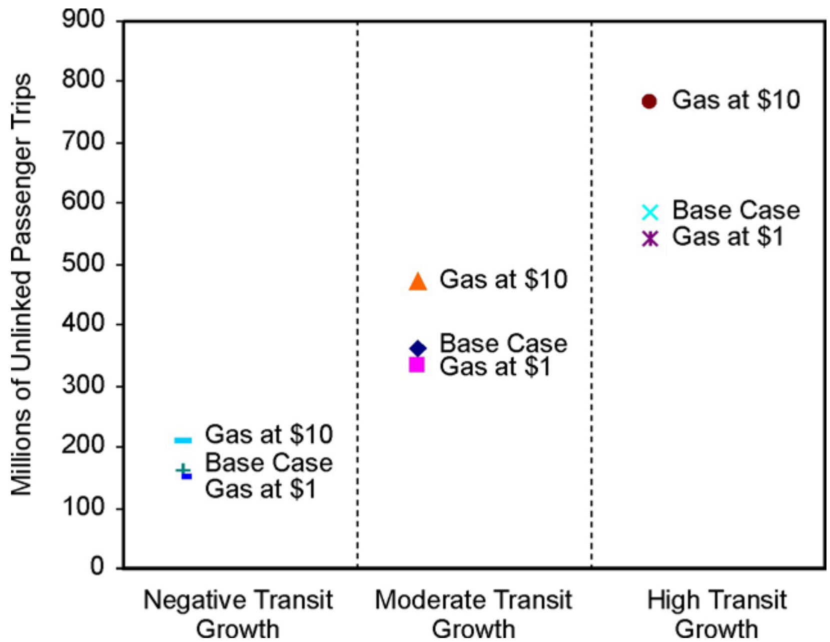

Figure 16. 2035 Passenger Transit Trips.

Base Case uses annual growth rates of –0.65%, 2.27%, and 4.07% for negative, moderate, and high transit growth for 2007 through 2035. Changes in fuel cost are relative to $2.80/gal (for year 2007, the last year for which transit data were available) (Hill, 2008) and a cross-elasticity of 0.12 (Litman, 2007).

External Influences Affecting Aviation Forecasts

A variety of factors may cause the number of enplanements to deviate from the number forecast. Such factors include the price of fuel, the threat of terrorism, an increase or decrease in system capacity, or a change in economic conditions. The 2035 estimate of 56.66 million enplanements is merely a best estimate based on the literature and does not address the uncertainty attributable to these factors.

A low Virginia enplanement forecast based on a reduction in GDP yields a low 2035 forecast of 26.82 million enplanements. This value represents only a 5% increase over the 2007 value, as shown in Figure 17.

A high Virginia enplanement forecast for 2035, developed by assuming that large domestic enplanements would grow at an annual rate of 2.97% (which was the annual growth rate in Virginia for the period 2000 through 2007 and is higher than FAA's baseline forecast of 2.5%), coupled with FAA's annual growth rates for regional and international enplanements (2.91%), suggests a total of 62.2 million enplanements in 2035. This estimate represents a 143% increase over the 2007 value, as shown in Figure 17.

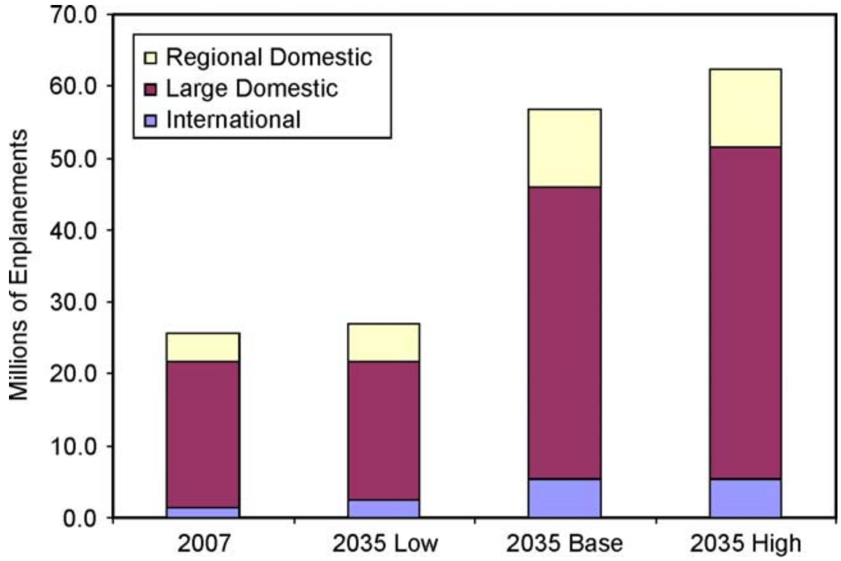

Figure 17. Forecasts of Growth in Enplanements for 2035.

2035 Low. Example: In 2007, Virginia had an estimated 3.764 million regional enplanements, which, assuming an FAA annual growth rate of 3.8%, suggests a baseline of 4.210 million regional enplanements in 2010. FAA (2008a) suggested that a low scenario might result in 2010 enplanements being 7.7% lower in 2010 than forecast, meaning Virginia's 2010 forecast would be (100% –- 7.7%)(4.210 M) = 3.886 million regional enplanements, which is an average annual growth rate (2007 to 2010) for regional enplanements of 1.06% (rather than the baseline forecast of 3.8%). Extending this 1.06% growth rate to 2035 suggests 5.1 million regional enplanements. Repeating similar calculations for large carrier domestic enplanements and international enplanements yields a total of 26.82 million enplanements in 2035.

2035 Base. Example: BTS data (2002) suggest Dulles had the following enplanement distribution in 2000: 11.77% (foreign air carriers); 69.08% (large certified air carriers); and 19.16% (commuter and small certificated air carriers plus air taxi commuter operators). Although recognizing there is not a perfect link between these three categories and those used by FAA (2008a), it was assumed that 11.77% of Dulles enplanements will grow at the average annual rates FAA projected for international enplanements (4.6%); that 69.08% of Dulles enplanements will grow at the rates projected for domestic enplanements by mainline carriers (2.5%); and that 19.16% of Dulles enplanements will grow at the rate projected for regional carriers (3.8%). Recall that Dulles had 11.8 million passengers in 2007. Thus, for 2035, Dulles 2035 baseline enplanements are forecast to be

$$(11.8\text{ M})\left\{(0.1177)(1.046)^{(2035-2007)} + (0.6908)(1.025)^{(2035-2007)} + (0.1916)(1.038)^{(2035-2007)}\right\} = 27.6\text{ M}.$$

Performing the same calculation for all airports in Table 7 yields a total of 56.66 M enplanements for year 2035.

2035 High. For 2000 to 2007, Virginia large domestic, regional domestic, and international enplanements grew at an average annual rate of 2.97%, 2.95%, and 2.91%, respectively. A "high" forecast was developed by choosing the larger of these rates and the projected annual growth rates from FAA (2008a), which were 2.5%, 3.8%, and 4.6%. The high forecast thus assumed that large domestic carrier enplanements will grow at 2.97% per year and that regional and international enplanements will grow at 3.8% and 4.6%, respectively.

Impacts of Four Potential Policy Responses to Challenges Raised by Forecasts

Impacts of Policy Response 1: Encourage Increased Density at Select Urban Locations to Reduce CO_2 Emissions

Table 8 suggested that increasing density could reduce DVMT by between 1.1% and 6.4% relative to the base case. (For example, the DVMT based on VEC population was 321.2 million DVMT, but increasing density could reduce this DVMT to 317.6 or 300.7 million DVMT, depending on the elasticity that was assumed.) To examine the impacts of increasing density at a finer level of detail and to consider an approach that gives latitude to Virginia regions, an alternative method of determining the impact of density was considered.

In this alternative method, no population was shifted among PDCs. Rather, for the four PDCs that will generate 81% of the population increase between 2010 and 2025, the AVMT was estimated for two scenarios. The first scenario was simply the base case where the 2035 densities were used with no modification. Under the second scenario, the two jurisdictions with the highest density were selected in each PDC and then the population growth for the entire PDC was divided evenly among those two jurisdictions, except in Northern Virginia as described in Appendix C. For each scenario, the AVMT was computed based on the literature (see Figure 18) and the percentage reductions between the increased density scenario and the baseline scenario were estimated.

Note that the AVMT values computed from this method are general values from the literature and may not directly correspond to the Virginia-specific DVMT estimates generated by Eq. 3. Thus the percentage reductions in AVMT between the baseline and the increased density scenario were applied to the baseline DVMTs (that is, the DVMTs computed via Eq. 3 for each PDC and that were shown in Table 4). Then, the difference in DVMT was multiplied by a composite emissions factor to estimate the amount of CO_2 eliminated by the reduced DVMT.

For example, the George Washington PDC may be considered. Table 9 shows that a total savings of 384.4 million AVMT would result if the population increase between 2010 and 2035 was diverted to the higher density portions of that PDC, such as the City of Fredericksburg, as opposed to the lower density portions, such as King George County. The reason for these reductions is that although the overall population of the PDC remains constant, more of the population falls to the right of Figure 18 where AVMT per person is lower. The reduction of 384.4 million AVMT shown in the bottom right cell of Table 9 is about 6.11% of the AVMT that

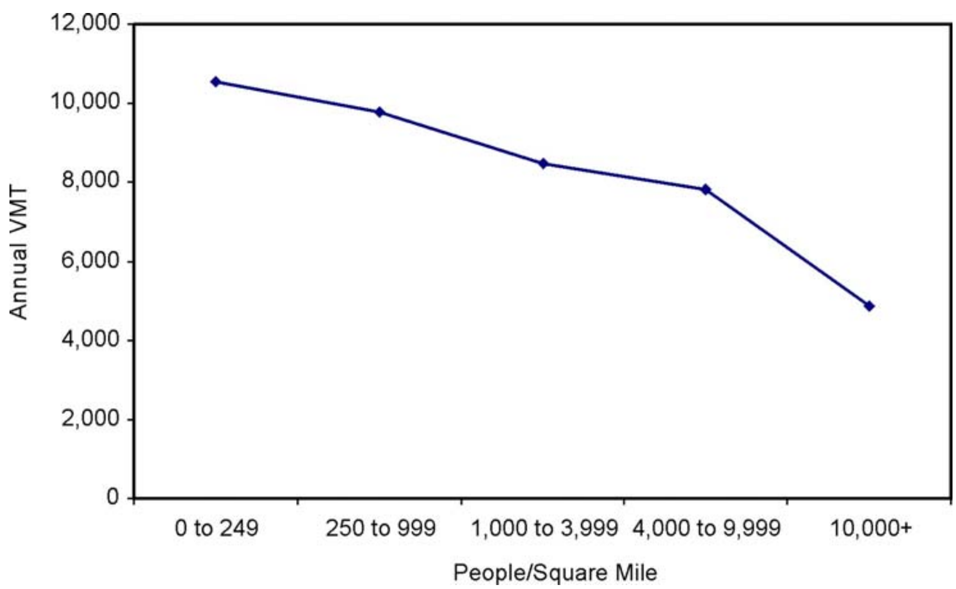

Figure 18. Annual Vehicle Miles Traveled (AVMT) As Function of Density.
Drawn from data provided by Ross and Dunning (1997).

Table 9. Example of How Modifying Density May Affect Annual Vehicle Miles Traveled (AVMT) Reductions in George Washington Regional Council

Jurisdiction	2035 Base Case			2035 Increased Density Case			Difference in AVMT (millions)
	Population	Density (people/ mi^2)	AVMT/ Person	Population	Density (people/ mi^2)	AVMT/ Person	
Caroline County	36,967	69	10,560[a]	28,030	53	10,560[a]	94.4[b]
King George County	35,861	199	10,560[a]	23,830	132	10,560[a]	127.0
Spotsylvania County and Fredericksburg City	299,150	727	9,762[a]	304,479	740	9,762[a]	–52.0
Stafford County	266,320	985	9,762[a]	281,959	1,043	8,458[a]	215.0
Total	638,298	458	9,853[c]	638,298[c]	458	9,251[c]	384.4

[a]AVMT were obtained from Ross and Dunning (1997) [see Table 8 within that source] as follows: 10,560 (density < 250 people/mi^2); 9,762 (250 < density < 999); 8,458 (1,000 < density < 3,999); 7,827 (4,000 < density < 9,999); 4,880 (density > 10,000).

[b] Example: Under the base scenario, there are 36,967 persons living in Caroline County in 2035. With an area of 532.52 mi^2, Caroline has a population density of 69 people/mi^2. With a density below 250 people/mi^2, each person generates an AVMT of 10,560 for a total 2035 AVMT of (10,560)(36,967) = 390.4 million AVMT. Under the increased density scenario, Caroline County would have only 28,030 persons who would generate 296.0 million AVMT, for a savings of 390.4 – 296.0 = 94.4 million AVMT.

[c] Computed by dividing the total AVMT by the total population. For example, under the 2035 base case, AVMTs by jurisdiction are 390.4 million (Caroline); 378.7 million (King George); 2,920.3 million (Spotsylvania and Fredericksburg); and 2,599.8 million (Stafford) for a total of 6,289.2 million for the PDC. Division of this total AVMT by the population of 638,298 yields a base case AVMT of 9,853 AVMT/person.

would be generated under the base case. Similar calculations, detailed in Appendix C, indicated AVMT reductions of 0.56% (Richmond Regional), 0.19% (Hampton Roads), and 6.82% (Northern Virginia).

The AVMT reductions in Table 9 and Table C1 in Appendix C are simply indications, based on the literature, of how increasing density can reduce AVMT. They are not, however, calibrated to Virginia; that is, they are not actual DVMT as calculated from Eq. 3. Thus, the percentage AVMT reductions from Tables 9 and B1 were applied to the DVMT estimates for each PDC shown previously in Table 5. For the sake of consistency, the numbers from just one column—the DVMT of 345.4 million—were used.

Table 10 shows the results of these calculations. Increasing the density in select jurisdictions within each PDC reduces DVMT by about 9.1 million, which is about 2.6% of the statewide total of 345.4 million DVMT. Table 10 suggests that this 9.1 million DVMT reduction translates into an annual savings of 1.507 million metric tons of CO_2.

A reasonable question is how the changes in density shown, shown in Table C1, affect the urban form of these areas. One way to answer this question is to compare the 2035 densities with the today's densities. Figure 19 shows that the 2007 densities of select Virginia jurisdictions ranged from a low of 6 people/mi^2 (Highland) to a high of 9,007 people/mi^2 (Alexandria). *Density* is defined as number of people living in an area per square mile; hence, these are residential rather than commercial densities. On a jurisdiction basis, the average density was 822 people/mi^2, similar to the Galax density of 825. On a population basis, one half of the population lives in an area with a density less than or equal to 1,054 people/mi^2 (Danville) and one half of the population lives an area with a density greater than or equal to

Table 10. Reduction in Carbon Dioxide Emissions

PDC	Baseline DVMT (millions)[a]	% Reduction in AVMT[b]	DVMT Reduction (millions)	Annual CO_2 Emissions Reduction (millions of metric tons)[c]
Northern Virginia Regional Commission	110.1	6.82%	7.5	1.242[d]
Richmond Regional	44.8	0.56%	0.2	0.041
George Washington RC	20.2	6.11%	1.2	0.204
Hampton Roads	65.1	0.19%	0.1	0.020
Other PDCs	105.1	--[e]		
Statewide total	345.4	--[e]	9.1	1.507[f]

[a] Portion of DVMT attributable to this PDC (see Table 4).
[b] Percentage reductions calculated from changing density in various jurisdictions (see Tables 9 and B1).
[c] Assumes that each DVMT generates 452.92 g in CO^2 emissions based on Table 18 in Appendix A of Feigon et al. (2003). The exact emissions for each vehicle will vary as a function of vehicle type, speed, and fuel. For example, modeling for one region of Virginia suggests an emissions factor of 473.44 g/VMT for all vehicles, with specific vehicle types having lower (e.g., 177.4 g/VMT for motorcycles) or higher (e.g., 1,412.9 g/VMT for heavy duty diesel vehicles) values (Ponticello, 2008).
[d] For example, Table 5 showed that based on the NPA population forecast for 2035 and Eq. 3, there would be 345.4 million DVMT, 110.1 million of which would be attributable to the Northern Virginia PDC. Table C1 showed that if increased density was sought in select Northern Virginia jurisdictions, a 6.82% reduction in AVMT might be achieved. Reducing Northern Virginia's 110.1 million DVMT by 6.82% yields a savings of 7.51 million DVMT. Multiplying these 7.51 million DVMT by 365 days/year and 452.92 g/VMT of CO_2 emissions yields about 1.24 million metric tons of CO_2 for Northern Virginia.
[e] Reductions in AVMT for the other PDCs were not tabulated as no change in density therein was assumed.
[f] Repeating this methodology but replacing the population from NPA (2008) with that of VEC (2008); replacing the 345.4 million DVMT baseline with the 321.2 million DVMT baseline; and replacing the emissions factor of 452.92 g/VMT with that of 473.44 g/VMT yields an emissions reduction of 1.563, rather than 1.507, million metric tons.

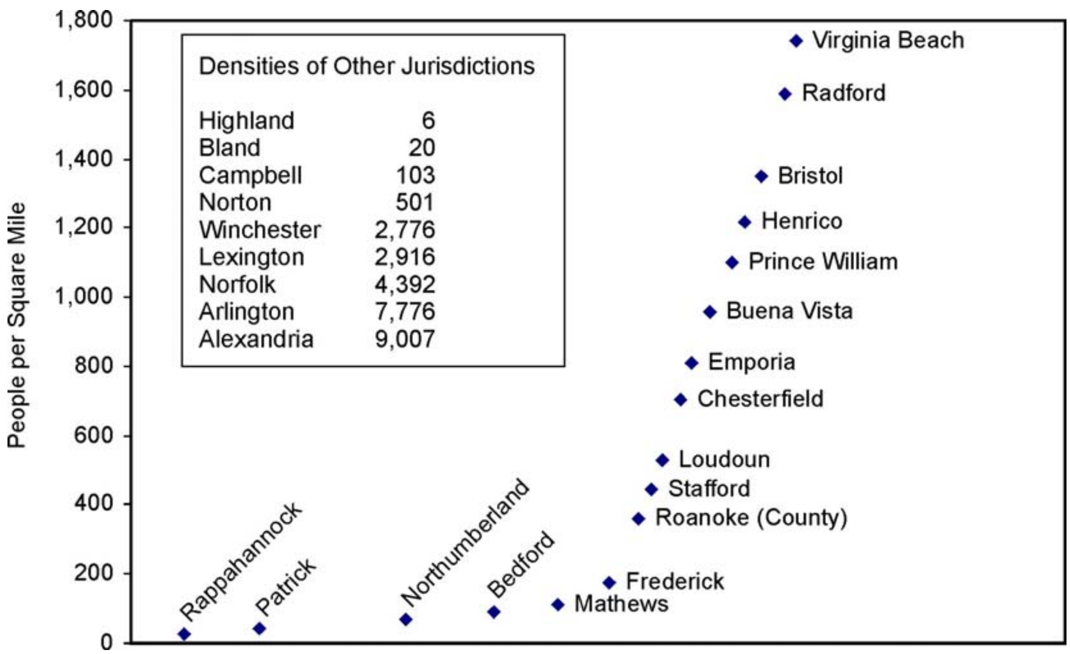

Figure 19. Residential Density of Select Virginia Jurisdictions in 2007.
Data were obtained from Weldon Cooper Center for Public Service (2003, 2008).

1,101 people/mi^2 (Prince William). One fourth of the state's population lived in an area with a population density no greater than that of Albemarle County (130 people/mi^2) and almost one third of the state's population lived in an area with a population density of at least 2,563 people/mi^2 (Fairfax County).

Thus, without exercising the policy response of increased density, the density of Henrico County / City of Richmond will be approximately 1,866 people/mi^2 in 2035 (slightly higher than the density of Virginia Beach at present). Exercising the policy response of increased density would increase the density to 2,306 people/mi^2, which is comparable to that of Colonial Heights at present (2,335 people/mi^2). The most dramatic increase would be that of Arlington plus Alexandria, which under the base case would increase to 9,773 people/mi^2. Under the increased density option, the density would increase to 13,171 people/mi^2, which is a higher density than any Virginia city at present.

Impacts of Policy Response 2: Use Cost-effectiveness As a Criterion to Select Project-Level Alternatives for Achieving a Particular Goal

Overview of Results of Case Study

As discussed in the "Methods" section, to determine the impact of selecting an alternative based solely on cost-effectiveness, a case study of the goal of reduced ground level ozone for 2035 was selected. Table 11 shows the impacts and compares the cost-effectiveness of the seven alternatives, previously discussed, for reducing NO_x emissions, a precursor of ground level ozone, generated by a 4-mile congested arterial facility. Appendix D documents the assumptions required to develop these cost-effectiveness estimates, which will vary based on site conditions.

The third column of Table 11 shows the extent to which VMT is reduced (for Alternatives 1-4) or speeds are increased (Alternatives 5-7). Based on Figures 2 and 3, the fourth column shows the reduction in NO_x emissions that results from each alternative. The fifth column shows the annual agency cost for each alternative. The last column shows the cost per kilogram of NO_x eliminated.

Interpretation of Results

The findings shown in Table 11 illustrate the criticality of using site-specific knowledge to achieve an emissions reduction at the lowest possible cost. For example, for this particular scenario, NO_x emissions are lower at 30 mph than at 40 mph, meaning that Alternative 7 (access management), which increases speeds only to 30 mph, has a better emissions impact on heavy vehicles than the HOV/HOT lanes alternative (Alternative 5), which increases speeds to 40 mph. The findings do not suggest that access management is universally preferable to HOV/HOT lanes. Rather, they suggest that knowledge of site-specific information could achieve an emissions reduction at a cost of $1,221/kg as opposed to $1,440/kg when comparing these two alternatives.

The results also show the utility of a specific goal for which public dollars are dispensed. Air quality may be considered as an example. If it had been the case that the region's ground

Table 11. Impact of Alternatives on DVMT/Speed Increase, NO_x Emissions, and Annual Agency Cost for Four-Mile Congested Arterial Facility

No.	Alternative	Reduction in DVMT or Increase in Speed (mph)	Reduction in NO_x Emissions (kg)	Annual Agency Cost (2007 dollars)	Average Cost/Kg NO_x Reduced
1	Encourage transit-oriented development (TOD)	0.300 M to 2.400 M[a]	89.70 to 717.60[b]	$367,909[c]	$2,307
2	Increase bus hours of service	0.099 M to 0.342 M[d]	29.60 to 102.26[b]	$84,980 to $293,567[e]	$2,871
3	Reduce transit fares	0.0255 M to 0.060 M[f]	7.62 to 17.94[b]	$28,264 to $66,503[g]	$3,707
4	Subsidize parking for 3+ carpoolers	0.230 M to 1.133 M[h]	68.77 to 338.87[b]	$287,500 to $1,416,667[i]	$4,181
5	Construct HOV/HOT lane (allow trucks)	5 to 20 mph[j]	240.40 to 363.20[k]	$358,277 to $474,925[l]	$1,440
6	Add HOT/HOV lane (no trucks)	5 to 20 mph[j]	110.0 To 190.00[m]	$465,760 to $617,403[l]	$3,887
7	Improve access management (construct frontage roads)	5 to 10 mph[n]	721.20 to 1,136.40[o]	$926,388 to $1,228,003[p]	$1,221

[a] TOD may increase the transit commuter mode share by 2% and 16% (Evans et al., 2007). Applying these percentages to 3,000 solo peak hour drivers and assuming five such peak hours per day suggest 300 to 2,400 new transit trips. At 4 miles per trip, this eliminates 1,200 to 9,600 DVMT or 0.3M to 2.4M AVMT.
[b] Figure 2 shows that the emissions factor for NO_x is 0.299 g/VMT at 20 mph. The reduced DVMT is multiplied by this amount and divided by 1,000 to yield a reduction in kilograms. For example, (0.3 M eliminated DVMT)(0.299 g/VMT)/1,000 = 89.70 kg.
[c] Cottrell (2007) reported that creation of a TOD in California necessitated two pedestrian bridges and bicycle path lighting improvements, at a capital cost of $5 million. A comparable level of investment in Virginia, amortized over a 20-year period with a 4% interest rate, suggests an annual cost of $367,909 per year.
[d] Evans (2004) indicated elasticities with respect to bus hours of service ranged from 0.33 to 1.14. Assuming each bus requires 1 hour, a doubling of bus hours should increase daily ridership by between 99 and 342 new riders, suggesting an AVMT reduction of (4 miles)(New riders = 99 or 342)(250 work days/year).
[e] Sinha and Labi (2007) reported that a single bus vehicle hour costs $102.38 (in 2005 dollars), which is $108.67 (in 2007 dollars). Assuming 1 vehicle hour per 20 passengers and a fare of $2, the agency cost of serving each additional rider would be $108.67/20 – $2 = $3.43, or $84,979 for 99 daily new riders at 250 days/year.
[f] McCollum and Pratt (2004) suggested that short-run fare elasticities vary between –0.17 (bus) and –0.40 (heavy rail), such that given a current fare of $2, a new fare of $1, 60 riders, and an elasticity of –0.17, the new ridership is

$$\text{New ridership} = \text{Base ridership}\left[\text{elasticity}\frac{\text{New Fare} - \text{Base Fare}}{\text{Base Fare}} + 1\right] = 60\left[(-0.17)\frac{\$1-\$2}{\$2}+1\right] = 65.1 \text{ per peak hour.}$$

This reduces DVMT by (5.1 riders)(5 peak hours)(4 daily miles/rider)(250 days/year) = 25,500 AVMT year.
[g] The additional cost includes $3.43 per rider as per Alternative 2 plus an extra $1 per rider for the fare subsidy.
[h] Kuzmyak et al. (2003) reported that the combination of parking charges and financial incentives associated with employer-based TDM programs yielded the following decreases in parking below current parking conditions without the programs: 6.9% (ample parking supply) and 34% (scarce parking supply). Assuming that 1,000 of peak hour users could participate in the program, participation rates would be between 69 and 340 per peak hour, suggesting an AVMT reduction of (250)(4 miles)(69 or 340 persons/peak hour)(5 peak hours)(2/3).
[i] Assuming a daily parking charge of $10 per day, a daily subsidy would be $10 per 3 participants. With 340 persons/peak hour, the annual cost is (340/peak hour)(5 peak hours)(250 days)($10/3) = $1,416,667.
[j] With imperfect compliance, speeds on the HOT/HOV lane are assumed to climb to 25 mph only. With better compliance, speeds are assumed to rise to 40 mph, which is a 20 mph increase in speeds.
[k] Figure 2 shows that at 20 mph, NO_x emissions factors for autos and trucks are 0.299 and 4.447 g/VMT; at 40 mph, these decrease to 0.261 and 4.014 g/VMT, respectively. The difference in these rates multiplied by the auto and truck DVMT using this lane yields the reduction in emissions. Assume one third of all traffic uses the HOV/HOT lane. The emissions reduction for autos is (0.299 – 0.261 g/VMT)(4 miles)(3,000 autos/peak hour)(1/3)(5 peak

hours/day)(250 days/year) = 190 kg and for trucks is (4.447 – 4.014 g/VMT)(4 miles)(240 trucks/peak hour)(1/3)(5 peak hours/day)(250 days/year) = 173.2 kg. The total emissions reduction is 190 + 173.2 = 363.2 kg.

[l] Sinha and Labi (2007) suggested that the cost of reconstructing and adding an urban divided section is $2.667 M per lane-mile (2.831 M in 2007 dollars). Given 4 lane-miles, a 20-year service life, and a 4% interest rate, the cost is $833,202 per year. Assuming that 50% of the costs are paid by tolls (for Alternative 6, this proportion is 35%), the agency cost is $416,601 per year. A 14% variation in costs is assumed based on literature that provided costs for median treatments (Bonneson and McCoy, 1997).

[m] NO_x calculations are identical to scenario 5 except no trucks use the lane, so there is no truck emissions reduction in scenario 6.

[n] Data from Gluck et al. (1999) suggest that reducing the number of access points per mile may increase free flow speeds by as much as 10 mph. A 5 mph increase is assumed as a lesser impact.

[o] Figure 2 shows that at 20 mph, NO_x emissions factors for autos and trucks are 0.299 and 4.447 g/VMT; at 30 mph, these decrease to 0.263 and 3.95 g/VMT, respectively. The emissions reduction for autos is (0.299 – 0.263 g/VMT)(4 miles)(3,000 autos/peak hour)(5 peak hours/day)(250 days/year) = 540 kg and for trucks is (4.447 – 3.95 g/VMT)(4 miles)(240 trucks peak hour)(5 peak hours/day)(250 days/year) = 596.4 kg for a total of 1,136.40 kg.

[p] The reduction in access points is expected to be achieved by the construction of frontage roads, for which a cost is suggested as $1,724 per lane-mile (in 2005) dollars (Sinha and Labi, 2007) Varying this figure by 14%, multiplying by 8 miles (4 miles per direction), and annualizing (20-year service life, 4% interest) yield the range shown in the table.

level ozone formation was VOC-limited, rather than NO_x-limited, then larger emissions reductions would occur at speeds of 55 mph or more rather than 35 mph (see Figures 2 and 3). This could affect the relative attractiveness of Alternatives 5, 6, and 7 which raise speeds by varying amounts.

It is also evident that the seven alternatives may have other effects and hence may represent opportunities for additional cost sharing. For example, with Alternative 1 (support TOD)m if the infrastructure investments could be shared with the private sector (cutting those costs in half), the cost per kilogram eliminated would be the lowest among the alternatives. A more striking example of the importance of site-specific assumptions is the relative cost-effectiveness of the HOV/HOT lanes with and without trucks (Alternatives 5 and 6). As tabulated, the elimination of trucks in Alternative 6 has a cascading effect of (1) eliminating the large emissions reduction benefit of heavy duty diesel vehicles traveling at higher speeds and (2) increasing agency costs by eliminating the tolls paid by these commercial vehicles.

Figure 20 demonstrates the importance of these site-specific assumptions. When these assumptions are changed as indicated in the figure, the most cost-effective alternative becomes Alternative 1 (TOD) rather than Alternative 7 (access management).

Finally, it is evident that funding for each of these seven alternatives might arise from different sources: for example, the transit operations budget that is the source of funds for Alternatives 2 and 3 would not fund the access management initiative in Alternative 7. Thus, the findings suggest that the ability to choose the most cost-effective alternative requires an ability to consider a variety of improvements without constraint by mode or funding source.

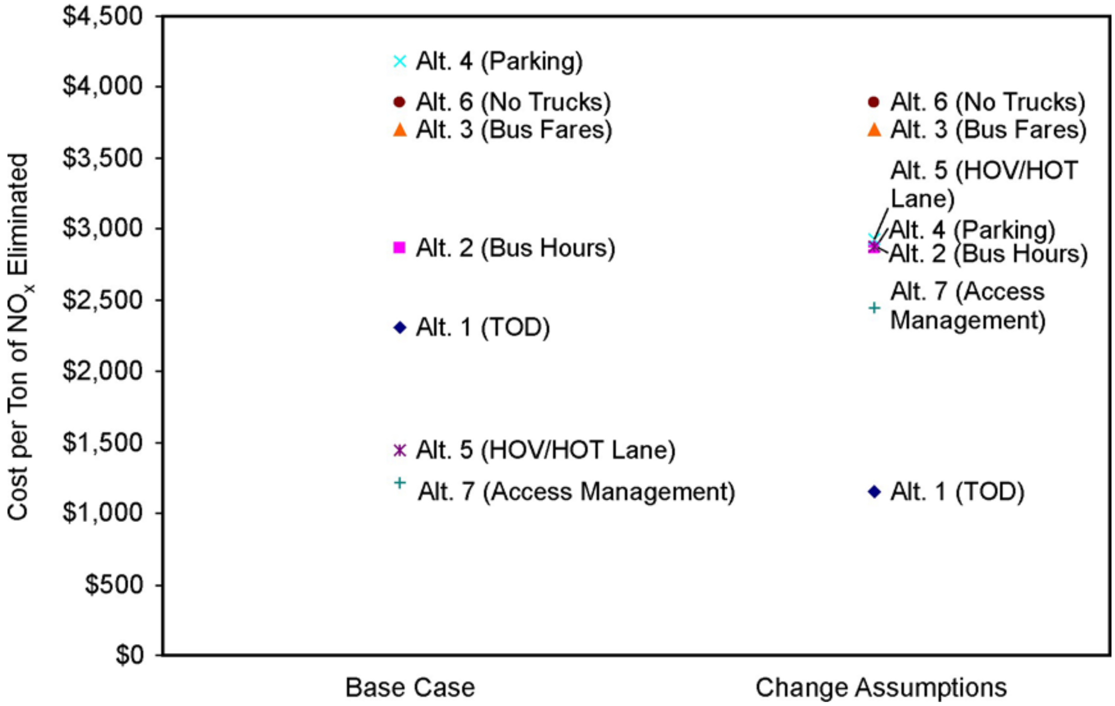

Figure 20. Impact of Changing Assumptions on Cost-effectiveness of Alternatives.
Changes to the assumptions were as follows: Alternative 1: only 1 bridge rather than 2 required (thus capital cost cut in half); Alternatives 2, 3, and 6: no change; Alternative 4: parking subsidy requires $7 rather than $10 per space; Alternative 5: technology shows that reversible lane not feasible such that 1 dedicated lane in each direction required if heavy trucks included; Alternative 7: right-of-way costs double capital investment necessary to construct frontage roads. HOV = high-occupancy vehicle; HOT = high-occupancy toll; TOD = transit-oriented development.

Impacts of Policy Response 3: Identify Policy Initiatives to Serve Increased Demographic Market Segments

Results of Case Study

As discussed in the "Methods" section, to determine the impact of this policy response, a case study of the market segment of persons age 65 and older was used

Figure 21 indicates that the proportion of persons age 65 and over will change from about 12% in 2010, to about 18% in 2030, to about 19% in 2035 (NPA, 2008). Thus, by 2035, the number of people over age 65 in Virginia may be double (1.96 million) that in 2010 (approximately 1 million). Figure 21 has another implication: in year 2010, the proportion of school age children (age 5 to 19) will be about 1.5 times the proportion of adults over age 65; by year 2035, these proportions will be roughly equal. Given that drivers age 65 and over make more than a one fourth of their trips during peak periods and that such drivers may constitute an even larger proportion of peak period travel (McGuckin and Contrino, 2008), the mobility needs for this demographic group merit consideration.

To address the needs of this population, the literature suggests several initiatives, some of which may be better known than others. Three are addressed here.

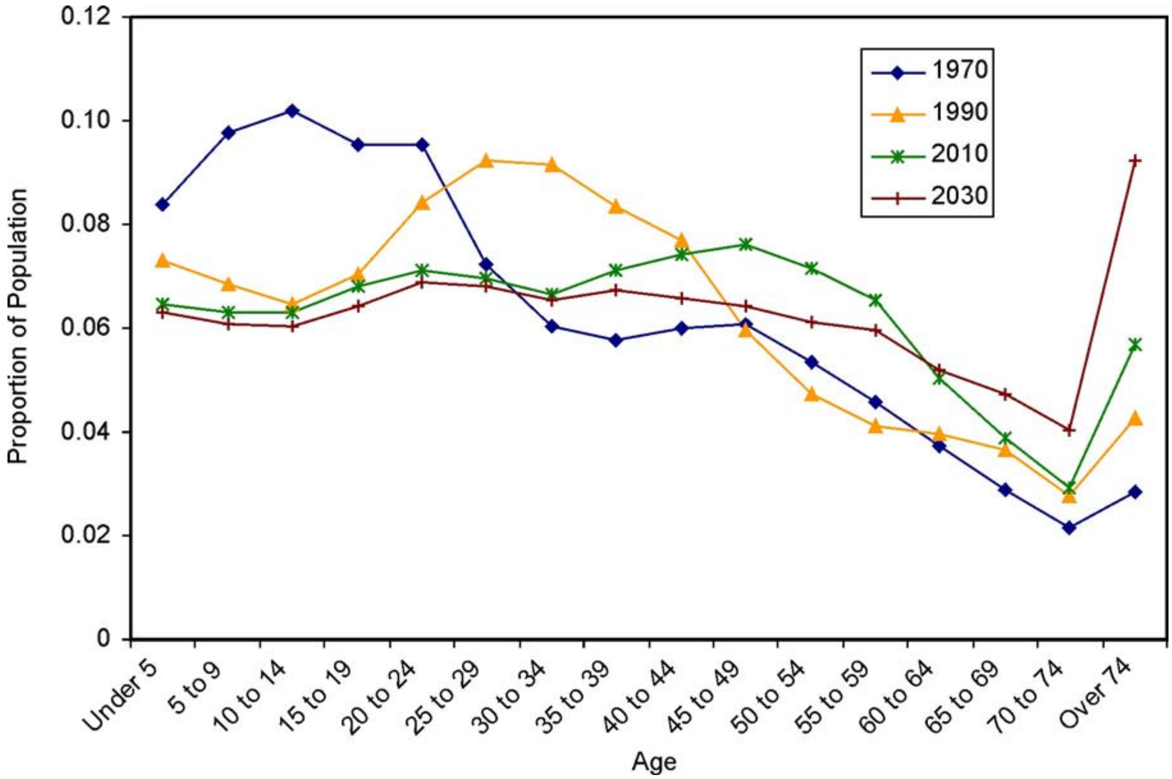

Figure 21. Distribution of Virginia Population by Age, 1970 to 2030.
Data were obtained from NPA (2008). Linear regression based on years 2026-2030 suggests that the proportion of persons age 65 and over will be 19% in 2035.

1. *Follow roadway design practices that are tailored to the needs of older drivers.* Examples in the literature (Staplin, 1998) include offsets for left turns (to facilitate viewing of opposing traffic when making a left turn), improved lighting at intersections, placards explaining the images that are used in pedestrian control devices, and backplates with traffic signals. Although additional research is still called for in select cases (e.g., Eby and Molnar [2008] suggested that roundabouts will probably reduce older driver crash risk but that no such study has quantified this risk in the specific case of older drivers), initiatives to design roadways in an age-friendly manner have received attention and are a component of Virginia's Strategic Highway Safety Plan (Virginia's Surface Transportation Safety Executive Committee, n.d.).

2. *Consider age-friendly land uses.* The literature (Coughlin, 2008; Rosenbloom and Herbel, 2008; Ward, 2008) recommends that the needs of older persons be expressly considered in land development while also noting that additional research is needed in this area. For example, Rosenbloom and Herbel (2008) posed the following as a question yet to be answered: Which land use concepts deal with aging-in-place as well as new communities? Although land use designs are suggested such as higher density and mixed use development in an area that can be supported by transit and with pedestrian-friendly features such as narrow streets and sidewalks, it is intriguing that the literature (Kochera et al., 2005) singles out two regulations that may have "unintended" (and adverse) consequences for this population: regulations that

prohibit multifamily dwelling units and regulations that prohibit “accessory dwelling units.” Kochera et al. (2005) also noted different satisfaction levels with communities when stratified by geography; for example, more suburban residents (25%) indicated poor marks for “dependable public transportation” than urban residents (14%).

3. *Consider initiatives to support persons who wish to continue driving.* The literature (Eby and Molnar, 2008; Rosenbloom and Herbel, 2008) distinguishes between two related goals: providing mobility options for persons who can no longer driver and assisting those who can and wish to drive to continue. Regarding the latter, Rosenbloom and Herbel (2008) suggested that, contrary to men, women may cease driving even though they can still safely do so (with one reason being that they are “disparaged” by their spouse). When it is necessary for these women to re-start driving (their spouse either dies or is incapacitated), it is difficult for them to do so because of the lack of recent driving experience. As a result, one area of exploration Rosenbloom and Herbel (2008) suggested is educational campaigns and training programs that address the needs of women and men separately. For example, Rosenbloom and Herbel (2008) reported that for men who stopped driving, the reason was often medical or vision problems (90%) but such problems were cited by less than one half of the women as the reason for their cessation of driving (46%). Eby and Molnar (2008) further reported that two disparate areas require further study as to their impact on safer driving: personal rehabilitation (e.g., treatments that strengthen the driver’s physical body or cognitive skills) and technological improvements to vehicles (e.g., changes to how a vehicle is steered to render it more age-friendly). Interestingly, the same authors noted that educational programs “may” increase the number of crashes for males age 75 and over.

The impact of these three initiatives is understood to varying degrees. Thus a state-level policy initiative would be to continue to explore the feasibility of these three initiatives through research; case studies; and, if merited, wider scale implementation. For example, in the short term (e.g., next 3 to 5 years), it may be possible to document better how particular roadway improvements, such as roundabouts, influence older driver safety at a particular location in Virginia. More time might be needed to determine the utility of programs that support older persons who wish to and are able to continue driving. Despite these differences in the state of the art, however, both areas appear productive for Virginia to explore further. In all three areas, the need for further research is acknowledged.

Thus, using the market segment of older drivers as an example, strategies may cut across diverse areas such as roadway engineering, land development, driver support, and vehicle adaptation.

Other Potential Market Segments

Another market segment is the transit dependent who relocate to areas with few transit services, perhaps because of changes in home prices. This segment is apparent in an urban revitalization effort within Baltimore’s “Middle East Urban Renewal Area” that is expected to shift transit-dependent residents from a location in the city with strong transit services to a portion of the city where fewer such services are available (Jones et al., 2008). For example, the authors noted that prior to the revitalization, one of the two census tracts in the affected area had a median 1999 household income of under $14,000 with 83% of renters and 57% of owners not having a vehicle available. Transit service was strong, with 253 transit stops located within one-half mile of the affected area. By contrast, one of the areas to which many of these residents located had only 81 transit stops and less use of transit as the commuting mode (Jones et al., 2008).

Another market segment is immigrants who rely on private shared transportation. Chatman (2008) suggested that most (82%) of the U.S. population increase through 2050 will be attributed to immigrants who arrive during that period and their U.S.-born descendents. As a consequence, the author argued that modes of transportation that serve a larger share of this population, such as "private shared transportation" (e.g., low-cost intercity bus service and low-cost commuter bus services, both of which are provided by private entities) merit greater attention, especially to the extent that some regulations may hamper such transportation services (Chatman, 2008).

Impacts of Policy Response 4: Quantify the Economic Harm of General Aviation Airport Closures

Link Between Aviation and Economic Growth

It is agreed that transportation influences economic growth. For airports in particular, the disparity in enplanement forecasts (between the low and high 2035 values) has direct economic implications for Virginia, given that previous work has shown, on average, that each enplanement in 2001 generated almost $700 in economic activity in 2007 dollars (BLS, 2008; DOAV, 2006a).

This economic activity reflects direct impacts (e.g., salaries paid to airport workers or additional lodging made possible by the airport), multiplier effects (e.g., the impact of an airport worker placing a portion of his or her salary into the local economy), and airport-dependent impacts. Airport-dependent impacts apply to businesses that rely on an airport for services such as "just in-time-shipping, a high degree of corporate travel, or specialized airport facilities and services such as free trade zones, U.S. Customs, and U.S. Immigration and Naturalization Services" and are measured as "local taxes, payroll, and local operating expenditures" made by such businesses (DOAV, 2006a). A total of $10.75 billion in economic activity (DOAV, 2006a) was generated in 2001 (in 2001 dollars), which, if divided by Virginia's 18.2 million enplanements in 2001 (FAA, 2008b), suggests $591.76 (in 2001 dollars) or $692.67 in 2007 dollars (BLS, 2008) for each Virginia enplanement. Based on 2007 enplanements, the 2007 economic impact is estimated to be $17.74 billion.

Based on 2035 enplanements, the high 2035 forecast suggests aviation could generate $43.12 billion in economic activity as opposed to the low 2035 forecast, which suggests a figure of $18.58 billion (all in 2007 dollars). Thus, relative to 2007, the low 2035 forecast represents a 5% increase in economic activity whereas the high 2035 forecast represents a 143% increase in economic activity

Potential Adverse Impacts Attributable to Airport Closure

Although a major component of Virginia airport economic contributions are from larger full service airports, general aviation airports are a component of the economic growth. Businesses may use presence of general aviation airports as a factor in deciding where to locate (DOAV, 2006b). Allen et al. (2006) reported that Virginia general aviation contributed $3.33 billion in output, employment, and earnings. The report does not specify the year of these dollars, but a review of the data sources suggests these are year 2004 dollars, which would be $3.66 billion in 2007 dollars.

It is possible that some general aviation airports may be at risk for closure or restriction of operations between 2010 and 2035. In some cases, closure may result because of economic pressures to use the airport land for other uses (e.g., residential development); in other cases, noise problems with land adjacent to the airport may lead to restricted operations (DOAV, 2006b). Although it is not clear what the reason for their closure has been, it was reported in 2006 that five local service airports had closed permanently and that three local service airports had closed to the general public (but were available for private use) (SH&E et al., 2006).

An implication of these closures is that the economic benefits of airports, cited as $18.58 to $43.12 billion in year 2035, could be less than this range if some airports that are contributors to this economic growth are closed.

Implementing the Proposed Policy Response

In this policy response, the economic harm of closing general aviation airports is quantified. Such information could be used in discussions with stakeholders, including localities, in an effort to keep these airports open. If justified, it is possible that public sector dollars could be used to purchase private airports that are under threat of closure.

Such quantification would need to isolate transfer impacts (e.g., the closure of an airport where business was moved to another Virginia county) from net loss impacts (e.g., the closure of an airport that resulted in the loss of business to another state).

The literature offers some insights into conducting such a study that focuses on airport closures. For example, in an explicit effort to study the economic impact of general aviation airports, Weisbrod (1990) surveyed Massachusetts business owners who used general aviation aircraft. More than 25% of the respondents reported that they would relocate (19%) or go out of business (7%), and an estimated 34% of respondents indicated that sales volume would contract. Based on this information, the author estimated that these figures put 40% of the sales at risk (because of relocation, going out of business, or a drop in sales). If applied to Virginia, such information could be used to determine the economic impact of individual airport closures.

DISCUSSION

Possible Error in Forecasts

Because forecasts are projections, some discussion of possible error in these projections, or uncertainty, is warranted. At least four factors influence this uncertainty:

1. *Various public and private providers may have different methodologies for developing projections.* For example, for Virginia's statewide population for year 2030, different forecasts of 9,825,019 (U.S. Census Bureau, 2005) and 10,316,340 (NPA, 2008) were given.

2. *Some projections are unavailable for some years and must be extended.* For example, although VEC (2008) provides population forecasts for individual jurisdictions, it does so only for year 2030, not year 2035.

3. *Not all forecasts can be made with equal precision.* For example, Missouri provided two estimates of annual population growth rate over a 6-year period: a low value of roughly 0.3% and a high value of 0.7% such that the size of this confidence interval was 0.7 – 0.3 = 0.4% (HDR/HLB Decision Economics, 2007). For the same time period, however, the size of the confidence intervals for personal income and fuel costs were much larger at 5.2% and 23.4%, respectively.

4. *Some trends simply cannot be envisioned.* For example, in 2005 an announcement was made that $270 million in private sector funds would be invested in Chesterfield [County] and Lebanon [town], both in Virginia, to support state government information technology efforts, bringing more than 400 jobs in information technology to southwest Virginia (Virginia Coalfield Economic Development Authority, 2005). Before the announcement was made, it would have been impossible to forecast precisely where new employment would occur or the number of jobs that would be created.

Thus it is expected that some forecasts, such as DVMT generated by a single county, will be less stable than others, such as the population of an entire state (Miller, 2003). It was appropriate, therefore, to show for each forecast a range that indicated the confidence one could have in the forecast. One would expect this range to be narrow for Virginia's population in 2035 but wide for the DVMT generated by Lebanon town residents in 2035.

Limitations of the Analysis

There are several limitations to a macroscopic analysis such as the one used in this study that can be resolved only at a finer level of detail. These limitations pertain to the estimation of statewide travel, the manner in which these variables are interpreted, the role of special generators, the granularity of the results, and the extent to which impacts of policy responses can be established.

Estimation of Statewide Travel

The first DVMT limitation pertains to correlation among key variables. Although Eq. 3 predicts DVMT solely as a function of population, several other factors—employment, income, and time—are also factors. While alternative approaches to Eq. 3 were tested, it was found that these four variables—population, employment, increases in household income, and the passage of time—were highly correlated for the period 1969 through 2007. (All correlations were between 0.957 and 0.998.) A related DVMT estimation issue pertains to data quality: DVMT tabulation methods changed between 1969 and 2007 as VDOT's traffic count program changed. Some question can be raised as to the transferability of forecasts: for example, Liu et al. (2007) noted that one of several reasons for their decreasing DVMT growth rates was the decreasing rate at which the number of households is growing in Pennsylvania. Virginia forecasts (NPA, 2008) show some attenuation in the annual increase in the number of Virginia households (e.g., the annual increase is 1.42% in 2010 compared to annual increases of 1.36% in 2020 and 1.39% in 2030). However, as discussed previously, this low forecast did align with the moderate forecasts based on Virginia-specific population estimates, which may increase one's confidence in the results.

Historical transit and aviation data are more limited than is the case for DVMT data. Transit data are available only to 1999 for smaller systems and to 1991 for larger transit systems, except for data for select systems in Northern Virginia where data are available for an earlier period from the Northern Virginia Transportation Commission. Aviation data are available only to 2000. A larger data limitation is that none of the forecasts explicitly modeled the impact of the current recession: all forecasts were completed by December 2008 and as of February 2009 the precise impacts of the current recession were not known.

Because transportation is a derived demand, it should ideally be linked to some measure of socioeconomic activity. Although this is the case for DVMT (based on population) and enplanements (based on FAA forecasts, which are believed to be related to GDP), the transit forecasts are based on the extrapolation of historical trends. To mitigate this weakness, three distinct historical trends—a large increase, a moderate increase, and a slight decrease in transit travel—were considered, which yielded a broad range of transit forecasts.

Manner in Which Variables Are Interpreted

Elasticities are valid only to the extent that demand continues to be influenced by the variable of interest, and thus the elasticity values, and hence the variables used herein require careful interpretation.

For example, the negative elasticity between DVMT and the price of unleaded gasoline may be considered. This elasticity is valid only to the extent that (1) alternative fuels are not available; (2) vehicle travel can be reduced; and (3) intervening actions do not occur that change the elasticity value. Three situations where this elasticity assumption might not hold are as follows:

1. *A rural county where the auto is the only travel option to reach a distant employment site*. (In this case, the increase in fuel costs may reduce expenditures in other areas but not necessarily DVMT, at least for the work trip.)

2. *A commuter who at present has a hybrid or electric-powered vehicle (short term) or an industry that is able to develop vehicles powered by alternative fuels (long term).* In practice, a very large increase in gasoline prices will indeed lead to reduced gas-powered travel but should not have the same effect on DVMT from electric-powered vehicles.

3. *A national policy of providing transit passes in response to concerns about fuel scarcity*.

In Item 1, the entire elasticity assumption is simply not valid: the increase in cost does not change the demand for travel. In Item 2, elasticity is still present but the assumption of linear elasticity does not necessarily hold, especially if economies of scale at some point suddenly reduce the cost of alternative-fueled vehicles. In Item 3, the elasticity value may change: a state policy of encouraging transit use may influence the response to vehicle travel, assuming the transit passes attract new users rather than simply subsidizing trips for existing transit riders.

A similar critique applies to density. Density by itself does not reduce DVMT; rather, higher density in some situations is associated with changes in other conditions conducive to a reduction in DVMT (Frank, 1998). Such conditions include, but are not limited to, increased transit service, pedestrian amenities, gridded streets, and mixing of land uses. Thus, it is assumed that the increase in density noted in the scenarios analysis would be accompanied by some of these conditions. It is conceivable, however, that density could be increased without any change in these other factors, under which case one would not expect DVMT to influence these results.

Finally, the elasticities used herein do not reflect second order responses. For example, if fuel costs increased, the elasticities might adequately capture the first order response of the resultant reduction in DVMT. However, a second order response might be a drop in revenue (because of the reduction in fuel taxes) where eventually the loss of revenue might eliminate needed capacity improvements that could further depress demand. An alternative second order response might be a change from a fuels tax to a VMT tax. Neither second order response is captured in this report, although the particular question of how a change in fuels tax might influence VMT is reported in another VTrans document (Virginia Transportation Research Council, 2008). That document states that a fuels tax remained a "viable revenue source" through year 2025 but that Virginia "will need to consider" a VMT-based tax in the "longer term."

Role of Special Generators

The DVMT estimates are an aggregate measure of travel demand and may not fully capture the impact of special generators, such as large employment centers or other facilities that attract large amounts of traffic. For example, increases in freight movements through the Port of

Virginia may generate higher levels of travel demand on corridors such as U.S. 58 and U.S. 460 (Florin, 2008).

Granularity of the Results

The aggregate nature of this analysis affects the results. For example, regarding Policy Response 1, it is possible that the emissions benefits of higher density are higher than those calculated here because the density calculations were performed at the geographic level of a jurisdiction (or in some cases multiple jurisdictions). Thus, some of the emissions reductions benefits of very high-density areas, such as the central business district of a given city, may not have been fully recognized in this report. It is also possible that the emissions benefits of higher density are lower than those calculated here, because CO_2 emissions are not directly proportionate to DVMT but rather are affected by other factors, such as speed (Sinha and Labi, 2007).

The literature reflects these other factors. For example, a 17% DVMT reduction was suggested (Bartholomew and Ewing, 2008) based in part on a 2050 horizon year and increased density; a 6% DVMT reduction was suggested by Stone et al. (2007) based on compact development patterns. Based on the density elasticity of –0.05 (Ewing and Cervero, 2001), a doubling of density in various Virginia jurisdictions would reduce DVMT by about 5%. There is a 25% difference in DVMT per household (Eads, 2007) when Atlanta (a low residential density, a large road density, and a poor supply of rail transit) and Boston (a high residential density, a smaller road density, and a better supply of rail transit) are compared. Given that Policy Response 1 used a 2035 horizon year and focused on density alone, the cited reduction of 2.6% or the range of 1.1% to 6.4% appears to be a reasonable order of magnitude.

Although the demand analysis focused on just a few factors—density, fuel cost, income, elasticity related to these factors, and annual growth rate in DVMT or transit trips—other factors may be studied. For example, decreases in funding for transportation or transit improvements (or the provision of existing services such as highway maintenance and bus operations) were not explicitly quantified but will also have an impact. (In September 2008, the Commonwealth Transportation Commissioner noted that Virginia's maintenance and operating budget was expected to decrease by $740 million over the next 6 years [Ekern, 2008].) Similarly a change in how transportation is funded—whether as a fuel tax, a VMT-based tax, or the increased use of privately tolled facilities—should influence the DVMT forecasts directly and, by extension, the transit-based forecasts and plausibly the regional portion of the aviation enplanement forecasts. Such cross-elasticities are not explicitly studied in this report.

Finally, analyses in addition to those presented in this report are feasible. For example, one way to analyze how high fuel costs might affect emissions is to estimate the emissions reductions attributable to a drop in fossil-based DVMT but then quantify the emissions that would result from additional electricity use presuming available technologies for such vehicles.

Extent to Which Impacts of Policy Responses Can Be Established

Although it was possible to quantify the impact of Policy Responses 1 and 2, it was not possible to quantify the impact of Policy Responses 3 and 4 at this point in time. In addition, other policy responses are feasible and may be more (or less) effective than those developed in this study.

Estimation of Statewide DVMT

Although uncertainty about the population and DVMT growth rate affect the statewide 2035 DVMT forecast, the uncertainty in DVMT attributable to growth rate is greater than the uncertainty attributable to population. The variation in DVMT based on different growth rates (483.6 versus 336.7 million DVMT) was larger than the variation based on different populations (345.4 versus 321.2 million DVMT).

Estimation of DVMT based on population (Eq. 3) yields a DVMT forecast similar to that presuming a low DVMT growth rate. Figure 13 shows that a population-based DVMT (321.2 or 345.4 million DVMT) is relatively close to a DVMT that presumes a low annual growth rate suggested by Liu et al. (2007) of 1.74% through 2010, 1.58% for 2011 through 2020, and 1.31% thereafter (336.7 million). A similar annual growth rate of 1.74% to 2% suggested by Polzin (2006) would yield 364 to 392 million DVMT, which is closer to the range of these three DVMT estimates (321.2 to 345.4 million) than the estimate based on a high DVMT growth rate (483.6 million DVMT). Thus, it appears that a lower rate of DVMT growth is likely than what was the case in the past.

Sensitivity of Travel Activity to Other Factors

Changes in density have the potential to reduce DVMT by between 1.1% and 6.4% relative to no change in density. The impact of increasing population density on DVMT was estimated from two types of sources: elasticity relationships (Table 8) and AVMT/density relationships from the literature that were then used to estimate DVMT reductions in Virginia (Table 10). The estimated DVMT reductions from both methods were comparable: the macroscopic method in Table 8 suggested reductions of between 3.8 and 22.0 million DVMT (hence a 1.1% to 6.4% reduction relative to the baseline value of 345.4 million DVMT), and the jurisdictional method of Table 10 suggested a reduction of about 9.1 million DVMT (hence a 2.6% reduction). The latter reduction suggests an annual emissions reduction of 1.507 million metric tons of CO_2.

Although changes in density affect DVMT, such DVMT changes are smaller than those that result from changes in fuel cost, income growth, and population growth. For the baseline case, for example, a macroscopic change in density reduced DVMT by between 3.8 and 22.0 million DVMT (between 1.1% and 6.4% of the total) depending on which elasticity was assumed. By contrast, Table 8 showed that a high fuel cost decreased DVMT by 168.7 million or 284.2 million DVMT (48.9% or 82.3% of the total) and low income growth decreased DVMT by 34.4 or 223.5 million DVMT (10% or 64.7% of the total) depending on which elasticity was assumed. Figure 13 also shows that the change in DVMT between the baseline case and the higher density case is *less* than the change in DVMT that results from two different statewide population estimates An implication of this finding is that although land use changes affect DVMT, a change may result if the state can influence more influential factors, such as the cost of fuel (or possibly investments in technology).

Although DVMT may be more sensitive to income than to fuel costs (Pickrell and Schimek, 1998), the analysis in this report suggests that higher fuel costs may cause a greater change in DVMT than a lowering of income. Table 8 showed that for the baseline case of 345.4 million DVMT, the DVMT based on high income growth (379.8 or 568.9, depending on elasticity) had an average value of 474.3. The difference between this average DVMT based on high income growth and the corresponding average DVMT based on low income growth is 257.9 million DVMT, which is not quite as large as the difference between DVMT based on high and low fuel costs (283.1 million DVMT). Figure 13 further shows that the change in fuel costs causes a moderately larger change in DVMT than the change in income. The explanation is that between 2010 and 2035, fuel costs could vary by as much as an order of magnitude (e.g., the high value of \$10/gal is *10 times* the low value of \$1/gal) whereas household incomes vary by a lesser amount (e.g., the high value of a doubling in household income is only *2 times* as large as the low value of no increase).

Figure 22 supports the inference that changes in fuel costs historically have been considerably more volatile than changes in household income. This is also evident from a correlation analysis: whereas population, employment, and income were highly correlated with DVMT (with values of 0.95 or higher), the correlation between fuel cost and income in a given year is weaker (–0.48). (The correlation analysis also suggests a time lag for fuel impacts, as a stronger correlation of –0.77 was found between fuel cost and DVMT 3 years later.)

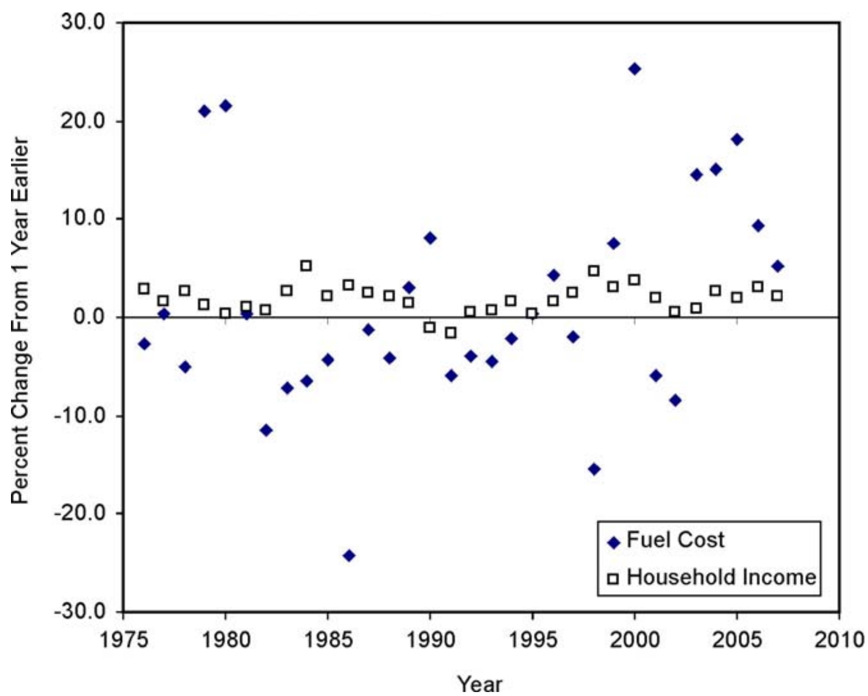

Figure 22. Percent Change in Household Incomes and Fuel Costs.
Household incomes in real dollars were obtained from NPA (2008). Fuel costs were obtained from EIA (2008) in nominal dollars; converted to constant dollars in accordance with BLS (2008).

Lessons Learned From the Impacts of the Four Policy Responses

The analysis of the impacts of the four policy responses suggested three insights.

1. *The ability to choose an alternative based solely on its ability to meet a single goal—and without constraint by project type—can greatly increase the cost-effectiveness of a project.* With Policy Response 2, where seven alternatives were considered such that the cost for reducing 1 kilogram of NO_x emissions ranged from $1,221 for the most effective alternative to $4,181 for the least effective alternative, the ratio the ratio of the least to most cost-effective was 3.42. When these assumptions were changed, a different alternative became the most cost-effective, but the ratio was similarly large, i.e., 3.37. The comparison shows the extent to which cost-effectiveness can be maximized if decision makers are able to concentrate on one goal, or a limited number of goals, and have flexibility in choosing alternatives such that the funding source (e.g., highway or transit, capital or operations) does not restrict the type of mode that must be favored.

2. *Implementation of the initiatives requires individuals with different disciplines.* Although Policy Responses 2 and 3 were very different in terms of scope (Policy Response 2 looked at emissions reduction measures, and Policy Response 3 identified methods to improve mobility for persons over age 65), they were similar in that they required expertise from fairly diverse disciplines. Policy Response 2 requires an ability to evaluate impacts of different modal solutions (access management, HOV/HOT lanes, and transit initiatives), and Policy Response 3 requires expertise in the areas of traffic engineering, safety, and driver education. Policy Response 4 necessitates an understanding of both the economic benefits of general aviation and local land development markets and ordinances. Given that the specific initiatives identified in Policy Response 3 require further research, being ready to study such different initiatives, or incorporate lessons learned from other states that implement such initiatives, will become increasingly important between now and 2035.

3. *Although the policy responses identified herein have merit, there does not yet appear to be a single solution that dominates all other alternatives.* Increasing density (Policy Response 1) yielded a small (but measurable) decrease in emissions. Having the freedom to choose the most cost-effective alternative (Policy Response 2) yielded some increase in cost-effectiveness, but a modest one. Identifying (and presumably implementing the most effective) initiatives for increasing older driver mobility (Policy Response 3) appears promising and critical, but the data do not yet enable identification of a single initiative that would be most productive. Being able to articulate economic benefits of modal preservation (Policy Response 4) should improve public accountability but does not eliminate the need to find funding sources. Thus the policy responses presented herein are feasible and appear promising relative to the "do nothing case" but have limited utility based on the data included in this report.

CONCLUSIONS

- *Socioeconomic activity and travel demand in Virginia are expected to increase from 2010 to 2035*. The best estimates for these increases are as follows:

  — Population: 28.3% (based on VEC data) or 35.6% (based on NPA data)
  — Employment: 48.9%
  — Household income: 50.21% in 2000 dollars
  — Employment to household ratio: 3.6% (statewide) with some higher increases (e.g., Northern Virginia with 7.3%), some lower increases (e.g., 2.2% in George Washington Regional), and some decreases (e.g., –10.3% in Rappahannock-Rapidan); these ratios exclude proprietor employment
  — DVMT (highway): 35.6% (based on the VEC population) or 44.8% (based on the NPA population)
  — Unlinked passenger trips (transit): 75.47%
  — Annual enplanements (aviation): 103.5%.

  Note also that the average household size will decrease by 3.1%.

  These best estimates depend on a wide variety of assumptions and may be replaced by a range. For example, the range of annual enplanements for year 2035 relative to 2007 is between 5% and 143% depending on GDP growth.

- *Although DVMT will increase, the annual rate of increase between 2010 and 2035 will be less than it was between 1982 and 2007*. A model predicting 2035 Virginia DVMT as a function of population forecast between 321 and 345 million DVMT, depending on which 2035 population is used. The application of low growth rates suggested by some literature yielded 337 million DVMT. All three estimates are substantially lower than what would result from the extension of historical Virginia DVMT growth rates between 1982 and 2007 (483.6 million DVMT).

- *Although statewide forecasts of DVMT, transit trips, and aviation enplanements have some uncertainty because of population, the uncertainty attributable to other factors, such as growth in household income, is larger*. Population uncertainty affected the 2035 DVMT estimate by a modest amount (321.2 to 345.4 million), whereas a change in household income caused a wider change in the forecast (113.3 to 529.0 million).

- *Although the four policy responses developed in this study may have merit, there is no "silver bullet*." For example, to the extent that density is a surrogate for other factors such as pleasantness of walking and proximity of destinations that may reduce automobile trip length or frequency, an increase in population density in select high-density jurisdictions may eliminate 1.507 million metric tons of CO_2 per year, based on the elimination of 9.1 million DVMT, which is 2.6% of the statewide 2035 DVMT. This change is smaller than changes in two different 2035 statewide population estimates (7.0% of DVMT), an increase in fuel costs to $10/gal (66% of DVMT), or elimination of the anticipated 50% increase in real household incomes between 2010 and 2035 (37% of DVMT).

- *The policy responses suggest that the challenges facing Virginia may possibly be addressed more effectively if alternatives can be selected based on their ability to achieve one or a small number of goals*. Policy Response 2 demonstrated that for a given goal, such as emissions reduction, the most cost-effective alternative may come from diverse areas (land use, highway construction, highway operations, transit construction, or transit operations) and thus flexibility to choose an alternative without modal restrictions may be beneficial. In the case study examined, the cost of the "best" alternative was less than one third that of the "worst" alternative—but site-specific information is needed to determine which alternative is best. This information is not necessarily available at the time of programming.

- *The range of potential policy responses is diverse in that different modes and different disciplines are required*. For the case study in Policy Response 3—identify policy initiatives to serve persons age 65 and over—included making roadway improvements amenable to older drivers and developing techniques, such as physical therapies and carefully targeted driver encouragement programs, that require a variety of skills.

- *Although DVMT is more sensitive to income than to fuel costs (Pickrell and Schimek, 1998), the analysis in this report suggests that changes in fuel cost may have a greater impact on fuel-based DVMT than changes in household income*. The explanation is that fuel costs between 2010 and 2035 could vary by as much as an order of magnitude (e.g., the high value of $10/gal of unleaded gasoline is *10 times* the low value of $1/gal) whereas household income is not assumed to have quite as large a range. Historical data suggest that fuel costs are more volatile than income.

RECOMMENDATION

This report found that four policy responses to the challenges posed by the changes facing Virginia by year 2035 have potential merit relative to the do-nothing case. Because this report did not *prove* that each policy response would be an effective use of resources, the four policy responses are only recommended *for consideration* at this point in time. These policy responses are:

1. *Encourage increased density at select urban locations to reduce CO_2 emissions*. The potential benefit of this response is a reduction in DVMT (a value of 2.6% was computed in this report). The potential disadvantage is that other factors, such as fuel price (and, as a consequence, policies based on fuel price), may have a greater impact.

2. *Use cost-effectiveness as a criterion to select project-level alternatives for achieving a particular goal*. The potential benefit of this response is an increase in cost-effectiveness (a ratio of about 3.37 to 3.42 between the least and most cost-effective project in this report was calculated). The potential disadvantage is that obtaining agreement on a single goal for a particular project can be difficult.

3. *Identify policy initiatives to serve increased demographic market segments*. The potential benefit of this response is identification of creative strategies to increase mobility; for example, given the expected doubling of persons age 65 and older by 2035 and the expected growth in DVMT, the strategy of enabling older drivers to continue driving (through traffic engineering and targeted educational campaigns) appears to have merit. The potential disadvantage of this response is that the costs of the various components of this strategy have not been assessed to determine which components are the most effective.

4. *Quantify the economic harm of general aviation airport closures.* The potential benefit of this response is that the results of such a study might enable the Commonwealth to preserve components of its air transport system. The potential disadvantage of this response is the cost of such a study.

COSTS AND BENEFITS ASSESSMENT

Four policy responses, selected because they require coordination across two or more transportation modes, were presented in this report. The costs and benefits of each policy response are highly variable and thus can be estimated at an accuracy of only an order of magnitude.

- *For Policy Response 1* (increased density in select urban locations to reduce CO_2 emissions), a rough estimate of the emissions benefits, once the policy is implemented, is a reduction of 1.5 million metric tons. To implement this policy response, an MPO would probably want to see a detailed study that quantified emissions reductions at a more detailed level of geography, such as that of a transportation analysis zone or census tract, than the jurisdiction level of geography used herein. The cost of such a study for each MPO, assuming one full-time employee (FTE) taking a full year, might be approximately $100,000. This cost could be raised or lowered depending on the extent to which existing models, such as the urban travel demand models, could be tailored to this purpose. Assuming four MPOs, the cost of implementing this policy response could thus be $400,000. Once the policy was implemented, there could be additional benefits (e.g., a reduction of necessary infrastructure) and additional costs (e.g., increased congestion levels). These ancillary benefits and costs have not been estimated.

- *For Policy Response 2* (choosing alternatives based on cost-effectiveness for a specific goal), the benefit is improved cost-effectiveness. The implementation cost is the controversy that may result from focusing on a single or limited number of goals without deference to mode.

- *For Policy Response 3* (identify policy initiatives to serve older persons), the benefit is possibly improved mobility options or safer travel for persons age 65 or over—a figure that will double in 2035 from year 2010. However, the benefit is also possibly nothing if, contrary to the hypothesis offered in this study, such an analysis does not result in any additional insights. The costs of implementing this policy are the costs associated with implementing the alternatives, and those costs cannot be estimated at this time.

- *For Policy Response 4* (quantifying the economic harm of general aviation airport closures), the possible benefit is preservation of some of the $3.66 billion in economic development contributed by such airports; however, if no airports are at risk of closure, there may be no benefit. The cost of this policy response is the cost of conducting the study, but this cost cannot be estimated at this time.

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REFERENCES

Allen, W.B., Blond, D.L., and Gellman, A.J. *General Aviation's Contribution to the U.S. Economy.* General Aviation Manufacturers Association, Washington, DC, 2006. http://www.gama.aero/PUBLIC/GAcontribution.pdf. Accessed December 12, 2008.

American Public Transportation Association. Virginia Transit Links. Washington, DC, 2003. http://www.apta.com/links/state_local/va.cfm. Accessed November 4, 2008.

Bartholomew, K., and Ewing, R. Land Use-Transportation Scenario Planning in an Era of Global Climate Change. In *TRB 87th Annual Meeting Compendium of Papers.* Transportation Research Board, Washington, DC, January 2008.

Beamer, B.D. *1994-1995 Report of the Secretary of the Commonwealth to the Governor and General Assembly of Virginia*. Office of the Secretary of the Commonwealth, Richmond, 1994.

Bureau of Labor Statistics. Consumer Price Index: All Urban Consumers, 2008. ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt. Accessed August 22, 2008.

Bureau of Transportation Statistics. *Virginia Transportation Profile.* Washington, DC, 2002. http://www.bts.gov/publications/state_transportation_statistics/virginia/pdf/entire.pdf. Accessed November 10, 2008.

Bonneson, J.A., and McCoy, P.T. *Capacity and Operational Effects of Midblock Left-Turn Lanes.* NCHRP Report 395. Transportation Research Board, Washington, DC, 1997.

California Planning Roundtable. *Deconstructing Jobs-Housing Balance.* 2008. http://www.cproundtable.org/media/uploads/pub_files/CPR-Jobs-Housing.pdf. Accessed January 8, 2009.

Capital Region Airport Commission. *Richmond International Airport Aviation Activity Report.* Richmond, 2008. http://www.flyrichmond.com/Site_Downloads/About_Downloads/Stats/RIC%20DEC07%20Activity%20Report.pdf Accessed November 10, 2008.

Chatman, D.G. Immigration Trends in the United States: Implications for Travel Demand, Transportation Systems, and Public Policy. Paper presented at the Transportation Research Board's Impact of Changing Demographics on the Transportation System Conference, Washington, DC, October 27-28, 2008. http://www.trb.org/conferences/2008/ImpactDemographics/pdf/chatman.pdf. Accessed December 11, 2008.

Choo, S., Lee, T., and Mokhtarian, P.L. Relationships Between US Consumer Expenditures on Communications and Transportation Using Almost Ideal Demand System Modeling: 1984-2002. In *Transportation Planning and Technology,* Vol. 30, No. 5, 2007, pp. 431-453. http://pdfserve.informaworld.com/593351_751309336_781771875.pdf. Accessed November 4, 2008.

Cottrell, W.D. Transforming a Bus Station Into a Transit-Oriented Development: Improving Pedestrian, Bicycling, and Transit Connections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2006.* Washington, DC, 2006, pp. 114-121.

Coughlin, J.F. Disruptive Demographics: Anticipating the New Demands of Aging on Tomorrow's Transportation System. Paper presented at the Transportation Research Board's Impact of Changing Demographics on the Transportation System Conference, Washington, DC, October 27-28, 2008.

http://www.trb.org/conferences/2008/ImpactDemographics/pdf/Coughlin.pdf. Accessed December 10, 2008.

Crichton, R. Email to Jack Jernigan. October 16, 2008.

Department of Aviation. *2004 Virginia Airport System Economic Impact Study.* Richmond, VA, 2006a. http://www.doav.virginia.gov/economic_impact_study.htm. Accessed November 7, 2008.

Department of Aviation. *A Guide to Compatible Airport Land Use Planning for Virginia Communities.* Richmond, 2006b. http://www.doav.virginia.gov/land_use_planning.htm. Accessed December 12, 2008.

Eads, G.C. The Worldwide Demand for Mobility and Its Impact on the Demand for 'Conventional' Oil. In *Modeling the Oil Transition: A Summary of the Proceedings of the DOE/EPA Workshop on the Economic and Environmental Implications of Global Energy Transitions*, D.L. Greene, ed., pp. 17-46. ORNL/TM-2007-014. Oak Ridge, TN, 2007. http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2007_014_EnergyTransitionsWorkshopSummary.pdf. Accessed November 3, 2008.

Eby, D.W., and Molnar, L.J. Safe Mobility of Older Adults. Paper presented at the Transportation Research Board's Impact of Changing Demographics on the Transportation System Conference, Washington, DC, October 27-28, 2008. http://www.trb.org/conferences/2008/ImpactDemographics/pdf/eby.pdf. Accessed December 11, 2008.

Ekern, D. Email to Staff of Virginia Department of Transportation. September 21, 2008.

The End of the Petrolhead. In The Power and the Glory: A Special Report on Energy, *The Economist,* June 21, Vol. 387, No. 8585, 2008, pp. 21-22.

Energy Information Administration. *August 2008 Monthly Energy Review: Table 9.4. Motor Gasoline Retail Prices, U.S. City Average.* Washington, DC, 2008. http://tonto.eia.doe.gov/merquery/mer_data.asp?table=T09.04. Accessed August 22, 2008.

Environmental Protection Agency. *MOBILE6 Vehicle Emission Modeling Software.* Washington, DC, 2007. Accessed November 24, 2008.

Evans, J.E., IV. *Transit Scheduling and Frequency: Traveler Response to Transportation System Changes*. TCRP Report 95 (Chapter 9). Transportation Research Board, Washington, DC, 2004.

Evans, J.E., IV, Pratt, R.H., Stryker, A., and Kuzmyak, J.R. *Transit Oriented Development: Traveler Response to Transportation System Changes*. TCRP Report 95 (Chapter 17). Transportation Research Board, Washington, DC, 2007.

Ewing, R., and Cervero, R. Travel and the Built Environment: A Synthesis. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1780.* Transportation Research Board, Washington, DC, 2001, pp. 87-114.

Federal Aviation Administration. FAA Aerospace Forecast, Fiscal Years 2008-2025. Washington, DC, 2008a. http://www.faa.gov/data_statistics/aviation/aerospace_forecasts/2008-2025/media/2008%20Forecast%20Document.pdf. Accessed November 6, 2008.

Federal Aviation Administration. *Passenger Boarding (Enplanement) & All-Cargo Data*. Washington, DC, 2008b. http://www.faa.gov/airports_airtraffic/airports/planning_capacity/passenger_allcargo_stats/passenger/index.cfm?year=all. Accessed November 7, 2008.

Federal Highway Administration. Estimated Lane-Length: 1980-1995 Lane-Miles by Functional System (Table HM-260). In *Highway Statistics Summary to 1995.* Washington, DC, 2002. http://www.fhwa.dot.gov/ohim/summary95/hm260.xls. Accessed November 5, 2008.

Federal Highway Administration. Vehicle-Miles of Travel, by Federal-aid Highways, 1966-1995 (Table VM-203). In *Highway Statistics Summary to 1995.* Washington, DC, 2003. http://www.fhwa.dot.gov/ohim/summary95/section5.html. Accessed October 17, 2008.

Federal Highway Administration. *Highway Statistics 2005.* Washington, DC, 2006. http://www.fhwa.dot.gov/policy/ohim/hs05/htm/vm2.htm. Accessed October 14, 2008.

Federal Highway Administration. Functional System Lane Length (Table HM-60). In *Highway Statistics 2006.* Washington, DC, 2007.

Federal Highway Administration. Quick Find: Roadway Statistics: Highway Statistics Series. Washington, DC, 2008. http://www.fhwa.dot.gov/policy/ohpi/qfroad.cfm. Accessed November 5, 2008.

Federal Transit Administration. National Transit Database: *TS1.1: Total Funding Time-Series.* Washington, DC, 2008a. http://www.ntdprogram.gov/ntdprogram/data.htm. Accessed September 2, 2008.

Federal Transit Administration. National Transit Database: *TS2.1: Service Data and Operating Expenses Time-Series by Mode*. Washington, DC, 2008b. http://www.ntdprogram.gov/ntdprogram/data.htm. Accessed August 28, 2008.

Feigon, S., Hoyt, D., McNally, L., Mooney-Bullock, R., Campbell, S., and Leach, D. *Travel Matters: Mitigating Climate Change with Sustainable Surface Transportation* TCRP Report 93. Transportation Research Board, Washington, DC, 2003. http://onlinepubs.trb.org/Onlinepubs/tcrp/tcrp_rpt_93.pdf. Accessed July 2, 2008.

Florin, J. Email to John Miller. October 16, 2008.

Frank, L.D. Improving Air Quality Through Growth Management and Travel Reduction Strategies. *ASCE Journal of Urban Planning and Development*, Vol. 124, No. 1, March 1998, pp. 11-32.

Froehlich, P. Travel Behavior Changes of Commuters from 1970-2000. In *TRB 87th Annual Meeting Compendium of Papers.* Transportation Research Board, Washington, DC, 2008.

Garrett, M. Email to John Miller. October 17, 2008.

Gluck, J., Levinson, H., and Stover, V. *Impacts of Access Management Techniques*. NCHRP Report 420. National Cooperative Highway Research Program, Washington, DC, 1999.

Hampton Roads Planning District Commission. *Current Membership*. Chesapeake, VA, 2008. http://www.hrpdc.org/Membership.asp. Accessed June 19, 2008.

HDR/HLB Decision Economics, Inc. Review and Critique MODOT'S State Revenue Forecasting Model. Silver Spring, MD, 2007. http://168.166.124.22/RDT/reports/Ri06024/or07013.pdf. Accessed July 3, 2008.

Hess, S., Smith, C., Falzarano, S., and Stubits, J. Measuring the Effects of Different Experimental Designs and Survey Administration Methods Using an Atlanta Managed Lanes Stated Preference Survey. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2049.* Transportation Research Board, Washington, DC, 2008, pp. 144-152.

Hill, C.T. Email to John Miller, October 17, 2008.

Hillier, F.S., and Lieberman, G.J. *Introduction to Operations Research.* Seventh Edition, McGraw-Hill, New York, 2001.

Jones, D., Irizarry, R., and Jha, M.K. The Impact of Urban Revitalization and Relocation on Transportation System Demand. Paper presented at the Transportation Research Board's Impact of Changing Demographics on the Transportation System Conference, Washington, DC, October 27-28, 2008. http://www.trb.org/conferences/2008/ImpactDemographics/pdf/Jha.pdf. Accessed December 10, 2008.

Kochera, A., Straight, A., and Guterbock, T. *Beyond 50.05: A Report to the Nation on Livable Communities: Creating Environments for Successful Aging.* Washington, DC, 2005. http://assets.aarp.org/rgcenter/il/beyond_50_communities.pdf. Accessed December 11, 2008.

Kuzmyak, J.R., Weiberger, R., Pratt, R.H., and Levinson, H.S. *Parking Management and Supply: Traveler Response to Transportation System Changes*. TCRP Report 95 (Chapter 18). Transportation Research Board, Washington, DC, 2003.

Litman, T. *Transit Price Elasticities and Cross-Elasticities.* Victoria Transportation Policy Institute, Victoria, British Columbia, Canada, 2007. http://www.vtpi.org/tranelas.pdf. Accessed June 25, 2009.

Liu, F., Kaiser, R.G., Zekkos, M., and Allison, C. Growth Forecasting of Vehicle Miles of Travel at County and Statewide Levels. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1957.* Transportation Research Board, Washington, DC, 2006, pp. 56-65.

McCollum, B.E., and Pratt, R.H. *Transit Pricing and Fares: Traveler Response to Transportation System Changes*. TCRP Report 95 (Chapter 12). Transportation Research Board, Washington, DC, 2004.

McGavock, A.T. Email to John Miller. October 23, 2008.

McGuckin, N., and Contrino, H. Peak Travel in America: Where Are We Going? Paper presented at TRB's Impact of Changing Demographics on the Transportation System, Washington, DC, 2008. http://www.trb.org/conferences/2008/ImpactDemographics/pdf/mcGuckin.pdf. Accessed December 10, 2008.

Middle Peninsula Planning District Commission. *Middle Peninsula Planning District Commission.* Saluda, VA, n.d. http://www.mppdc.com/. Accessed June 19, 2008.

Miller, J.S. *Expected Changes in Transportation Demand in Virginia by 2025.* VTRC Report 03-TAR5. Virginia Transportation Research Council, Charlottesville, 2003. http://www.virginiadot.org/vtrc/main/online_reports/pdf/03-tar5.pdf. Accessed June 12, 2009.

NPA Data Services, Inc. 2007 Regional Economic Projection Series: Economic, Household, & Demographic Totals, 1969-2030, State Service Virginia. CD. Alexandria, VA, 2008.

Office of Intermodal Planning and Investment. VTrans 2035. Richmond, n.d. http://www.vtrans.org/. Accessed February 10, 2009.

Pickrell, D., and Schimek, P. *Trends in Personal Motor Vehicle Ownership and Use: Evidence from the Nationwide Personal Transportation Survey.* U.S. DOT Volpe Center, Cambridge, MA, 1998. http://nhts.ornl.gov/1995/Doc/Envecon.pdf. Accessed July 3, 2008.

Polzin, S.E. *The Case for Moderate Growth in Vehicle Miles of Travel: A Critical Juncture in U.S. Travel Behavior Trends.* U.S. Department of Transportation, Office of the Secretary of Transportation, 2006. http://www.cutr.usf.edu/pdf/The%20Case%20for%20Moderate%20Growth%20in%20VMT-%202006%20Final.pdf. Accessed July 2, 2008.

Ponticello, J. Email to John Miller, November 3, 2008.

Ravanbakht, C. Email to John Miller, May 22, 2008.

Rosenbloom, S., and Herbel, S. The Safety and Mobility Patterns of Older Women in 2030. Paper presented at TRB's Impact of Changing Demographics on the Transportation System, Washington, DC, 2008. http://www.trb.org/conferences/2008/ImpactDemographics/pdf/rosenbloom.pdf. Accessed December 10, 2008.

Ross, C.L., and Dunning, R. *Land Use Transportation Interaction: An Examination of the 1995 NPTS Data.* U.S. Department of Transportation, Office of the Secretary, Washington, DC, 1997. http://nhts.ornl.gov/1995/Doc/landuse3.pdf. Accessed June 15, 2009.

Schinkel, T.O. Email to John Miller. November 13, 2008.

SH&E, HNTB, and Talbert & Bright. *The Virginia Air Transportation System Update: 2003 Technical Report.* Department of Aviation, Richmond, 2003. http://www.doav.virginia.gov/Downloads/Studies/VATSP%20Update/VATSP%20Update%20Technical%20Report%202003.pdf. Accessed November 12, 2008.

Sinha, K.C., and Labi, S. *Transportation Decision Making.* John Wiley & Sons, Inc., Hoboken, NJ, 2007.

Staplin, L., Lococo, K., and Byington, S. *Older Driver Highway Design Handbook.* Federal Highway Administration, Washington, DC, 1998. http://www.tfhrc.gov/safety/pubs/97135/index.htm. Accessed January 29, 2008.

Stone, B., Mednick, A.C., Holloway, T., and Spak, S.N. Is Compact Growth Good for Air Quality? *Journal of the American Planning Association*, Vol. 73, No. 4, 2007, pp. 404-418.

Strobel, F.R. Make Us Pay $10 per Gallon for Gas. *St. Petersburg Times,* June 15, 2008.

Sun, X., Wilmot, C.G., and Kasturi, T. Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Activity-Based Travel Survey. In

Transportation Research Record: Journal of the Transportation Research Board, No. 1617. Transportation Research Board, Washington, DC, 1998, pp. 10-17.

Taube, R.K. Case Study of the Washington Metropolitan Area Transit Authority. Paper presented at the Virginia Annual Transportation Conference, Roanoke, November 8, 2007. http://www.thinkoutsidethecar.org/pdfs/Virginia%20Annual%20Transportation%20Conference.pdf. Accessed August 28, 2008.

Terleckyj, N. Email to John Miller, June 17, 2008.

U.S. Census Bureau, Population Division, Interim State Population Projections, Table 1: Interim Projections: Ranking of Census 2000 and Projected 2030 State Population and Change: 2000 to 2030, Washington, DC, 2005. http://www.census.gov/population/projections/PressTab1.xls. Accessed June 16, 2008.

Virginia Coalfield Economic Development Authority. Governor Warner Approves Nation's Most Sweeping Public/Private Partnership in Technology. Press Release. Richmond, VA, November 14, 2005. http://www.vaceda.org/news_november14_2005.asp. Accessed March 21, 2008.

Virginia Department of Transportation. *Average Daily Traffic Volumes on Interstate, Arterial, and Primary Routes*. Annual Reports. Richmond, 1969-2007.

Virginia Department of Transportation. 2005 Traffic Data: DVMT by Physical Jurisdiction All Roads. Richmond, 2006. http://www.virginiadot.org/info/resources/VMTReport_1200_2005.xls. Accessed October 14, 2008.

Virginia Department of Transportation. 2006 Traffic Data: DVMT by Physical Jurisdiction. Richmond, 2007. http://www.virginiadot.org/info/resources/VMTReport_1200_2006.xls. Accessed August 22, 2008.

Virginia Department of Transportation. *Summary State Highway Systems*. Richmond, 2009. http://mileagetables.virginiadot.org/default.asp?Content=Summary&Table=66&DrillDown=False. Accessed January 5, 2009.

Virginia Employment Commission. Download Center: Index of lmi/data/population. Richmond, May 20, 2008. http://www.alex.vec.state.va.us/lmi/data/population/popproj.xls. Accessed June 16, 2008.

Virginia's Surface Transportation Safety Executive Committee. *Commonwealth of Virginia's Strategic Highway Safety Plan: 2006-2010*. Richmond, n.d.

http://www.virginiadot.org/info/resources/Strat_Hway_safety_Plan_FREPT.pdf. Accessed December 11, 2008.

Virginia Transportation Research Council. *Examining the Long-Term Viability of the Motor Fuels Tax and Possible Alternatives*. Office of Intermodal Planning and Investment, Richmond, VA, 2008. http://www.virginiadot.org/projects/vtransNew/resources/FINALVTans_1-13-09.pdf. Accessed February 10, 2009.

VTrans2025 Technical Committee. *VTrans2025: Virginia's Statewide Multimodal Long-Range Transportation Plan: Phase 3 and Final Report to the General Assembly.* Richmond, November 17, 2004. http://www.virginiadot.org/projects/vtrans/resources/revisedPhase3Reportforctb.pdf. Accessed March 18, 2009.

Wadud, Z., Graham, D.J., and Noland, R.B. Gasoline Demand with Heterogeneity in Household Responses. In *TRB 87th Annual Meeting Compendium of Papers.* Transportation Research Board, Washington, DC, 2008.

Ward, B.G. Aging in Black America: Cultural Practices, Challenges, and Opportunities. Paper presented at *TRB's Impact of Changing Demographics on the Transportation System*, Washington, DC, 2008. http://www.trb.org/conferences/2008/ImpactDemographics/pdf/ward1.pdf. Accessed December 10, 2008.

Weisbrod, G. Economic Impacts of Improving General Aviation Airports. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1274.* Transportation Research Board, Washington, DC, 1990, pp. 134-141.

Weldon Cooper Center for Public Service, Demographics & Workforce Section. *Population, Housing Units, Area, & Density for Virginia Counties & Cities, 2000*. Charlottesville, VA, 2003. http://www.coopercenter.org/demographics/sitefiles/documents/excel/lists&definitions/density-county.xls. Accessed August 13, 2008.

Weldon Cooper Center for Public Service, Demographics & Workforce Section. Population Estimates for Virginia, Localities, Planning Districts, & Metropolitan Areas: Final 2006 & Provisional 2007. Charlottesville, VA, 2008. http://www.coopercenter.org/demographics/sitefiles/documents/excel/populationestimates/2007_va_population_estimates.xls. Accessed June 16, 2008.

Whaley, J.W. The Long-Range Forecast. Presentation to the Hampton Roads Planning District Commission, Chesapeake, VA, 2007. http://www.hrpdc.org/Presentations/ECON/2007/2034%20Forecast.pdf. Accessed June 16, 2008.

Zhang, L., and McMullen, B.S. Statewide Distance-Based User Charge: The Case of Oregon. In *TRB 87th Annual Meeting Compendium of Papers.* Transportation Research Board, Washington, DC, 2008.

APPENDIX A

CALCULATING THE RATIO OF JOBS TO HOUSEHOLDS FOR 2035

The ratio of jobs to households used in this report was calculated by dividing the number of wage and salary jobs by the number of households. Based on the information provided in this appendix, wage and salary jobs provided by NPA (2008) are most comparable to wage and salary jobs from the Bureau of Economic Analysis (BEA), and the household forecasts are most comparable to occupied housing units provided by the Census (2008). This appendix summarizes different approaches for computing jobs to household ratios and explains why the particular approach used in the current report was chosen for Virginia 2035 forecasts.

Wage and Salary Employment

The BEA defines *wage and salary employment* as the "average annual number of full-time and part-time jobs in each area by place-of-work" (BEA, 2008b). Although nonfarm wage and salary employment is also captured by the Bureau of Labor Statistics (BLS), the BLS figures are lower than those reported by BEA, in part because the BLS data do not include certain employment categories such as forestry, fishing, hunting, the military, "other" (BEA, 2008a), and domestic workers (BLS, 2007). Thus, 2005 Virginia wage and employment data reported by BLS are about 7% lower than those reported by BEA.

Proprietor Employment

BEA also captures proprietor employment, such as self-employed individuals who file a Schedule C with the Internal Revenue Service. BEA defines *proprietor employment* as the "number of sole proprietorships and the number of individual business partners not assumed to be limited partners" (BEA, 2008b). In Virginia in 2005, such employment accounted for approximately 16% of total employment. These data are not captured by BLS.

Summary of Employment Categories

Table A1 summarizes Virginia employment estimates for year 2005 from BLS (upon which the Virginia Employment Commission [VEC] figures are based) and BEA (upon which the NPA figures are based). Table A1 also shows farm employment, which is captured by BEA but not by BLS. Consistent with the literature (Evans, 1998; U.S. Department of Transportation, 2008), a total employment figure obtained from BEA will be higher than a total employment figure obtained from BLS.

Table A1. Virginia Employment Data, 2005

Employment Category	BLS (2007)	BEA (2008c)	NPA (2008)
Wage and salary (farm)	N/A	9,150[a]	8,690[a]
Proprietor (farm)	N/A	47,833	47,820
Wage and salary (nonfarm)	3,664,400	3,937,705[b]	3,938,160[b]
Proprietor (nonfarm)	N/A	717,748	734,290
Total employment	N/A	4,712,436	4,728,960

BLS = Bureau of Labor Statistics; BEA = Bureau of Economic Analysis; NPA = NPA Data Associates, Inc.
[a]Farm wage and salary employment is derived by subtracting farm proprietor employment from total farm employment.
[b]Nonfarm wage and salary employment is derived by subtracting farm wage and salary employment from total wage and salary employment

Choosing an Employment Category for the Jobs to Household Ratio

To compute a jobs to household ratio, this report uses *wage and salary employment* rather than *total employment; thus proprietor employment was not used in the jobs to household ratio provided in this report.* The location of the wage and salary employment is the jurisdiction in which the job is located. Thus, if a worker lives in Region A and works in Region B, the worker's place of employment is listed as Region B.

By contrast, the location of the proprietor employment is "largely" the place of residence rather than the place of work of the individual (BEA, 2008b). This definition of *location* does not necessarily mean a proprietor works at home but rather reflects "limitations in source data" (BEA, 2008b). The implication, therefore, is that if a self-employed individual who files a Schedule C lives in Region A and works in Region B, then that individual's place of employment is listed as Region A.

The decision to use wage and salary employment, rather than total employment, has both a strength and a weakness when determining a jobs to household ratio. The advantage is one of data integrity: one can be reasonably confident that the place of employment used in the ratio is accurate. The disadvantage is one of data completeness: for 2005 in Virginia, about 16% of jobs were excluded from the computation.

Extent to Which Excluding Proprietor Employment Affects the Jobs/Household Ratio

Table A2 shows, for a hypothetical region and state, jobs to household ratios based on wage and salary employment only and on total employment. An examination of this table shows the extent to which excluding proprietor employment affects the jobs to household ratio provided in this report.

As an example, just the 30 proprietor employment jobs shown for Region A in the table may be considered. The location of these jobs is Region A, regardless of whether the individuals performing the jobs physically work in Region A (e.g., at home) or in another region (e.g., a contract employee who travels to a publishing office in Region B to work). Whether a

Table A2. Jobs to Household Ratios For a Hypothetical Year Based on Wage and Salary Employment Only and on Total Employment for a Hypothetical Region and State

Location	Employment (jobs)		Households	Calculated Jobs/Household Ratio Based on	
	Wage and Salary Employment	Proprietor Employment		Wage and Salary Employment	Total Employment
Region A	90	30	67	90/67 = 1.34	120/67 = 1.79
Entire State	1,500	300	1,000	1,500/1,000 = 1.5	1,800/1,000 = 1.8

jobs/household ratio based on wage and salary employment is more accurate than one based on total employment depends on where these 30 jobs are physically located.

- *If all 30 proprietor employment jobs are physically located within Region A*, Region A has 120 jobs and 67 households, for a ratio of 1.79 comparable to the statewide average of 1.8. Therefore, the ratio based on *total employment* gives a more accurate measure of the jobs to household ratio, with the interpretation being that jobs/household ratio for Region A is comparable to that for the state.

- *If none of the 30 proprietor employment jobs is physically located in Region A*, in reality, Region A has only 90 jobs relative to 67 households, for a ratio of 1.34. Therefore, the jobs/household ratio for Region A is below that for the state. In that sense, therefore, the ratio based on wage and salary employment is more accurate.

Estimation of Households

This report estimates the denominator in the jobs/household ratio as the number of households, which is defined as the number of occupied housing units (U.S. Census Bureau, n.d.a). The reason for this decision is that forecasts of households, as opposed to housing units, are available to year 2035.

An alternative approach would be to estimate the denominator as the total number of housing units, which in 2005 were approximately 10% higher than the number of occupied housing units (households), as shown in Table A3.

Examples can be found in the literature that use population, households (occupied housing units), and total housing units as the denominator in the jobs/household ratio, and in some cases, the terms are used synonymously. Bento et al. (2003) noted the need to assess “the location of employment relative to population, or jobs-housing balance,” which they computed by tracking jobs and population. By contrast, the King County Budget Office (2004) used

Table A3. Households and Housing Units in Virginia in 2005

Data Source	U.S. Census	U.S. Census	NPA
Units	Total Housing Units	Households	Households
Value	3,178,385[a] or 3,174,708[b]	2,889,688[c]	2,869,790[d]

[a] U.S. Census Bureau (2008).
[b] U.S. Census Bureau (2006).
[c] U.S. Census Bureau (n.d.b).
[d] NPA Data Services, Inc. (2008).

housing units in the denominator (and stated that there is not a "benchmark target for the 'right' ratio of jobs to housing"). Occupied housing units (e.g., households) were used to yield a jobs/housing ratio in the Los Angeles Area (Singa et al., 2004) and are reported elsewhere as "the most common" indicator of the ratio of jobs to housing (California Planning Roundtable, 2008). However, it has also been noted that *total housing units* may be used instead of occupied housing units (households) because some communities may find it easier to track total housing units rather than the ones that are vacant (California Planning Roundtable, 2008).

Summary

Returning to Table A1 and Table A3, the methodology used in this report yields the following jobs to household ratio for the year 2005 as follows:

1. Wage and salary employment for 2005 (not including proprietor employment) is approximately 3.946 million.

2. Households (not including vacant housing units) for 2005 is approximately 2.890 million.

3. The ratio of jobs to households for 2005 therefore, is 3.946/2.890 = 1.37.

Thus, when considering the ratios forecasted in this report for the year 2035, the following should be noted. *Lower* jobs to household ratios than those computed in this report may be expected if total dwelling units rather than occupied dwelling units are used for "household" or if BLS data, which exclude certain employment categories such as forestry, are used. *Higher* jobs to household ratios than those computed in this report may be expected if proprietor employment rather than only wage and salary employment is included in "jobs."

References

Bento, A.M., Cropper, M.L., Mobarak, A.M., and Vinha, K. *The Impact of Urban Spatial Structure on Travel Demand in the United States.* The World Bank Development Research Group, Washington, DC, 2003. http://ntl.bts.gov/lib/24000/24400/24492/24989_wps3007.pdf. Accessed January 7, 2009.

Bureau of Economic Analysis. *Local Area Personal Income and Employment Methodology.* Washington, DC, 2008a. http://www.bea.gov/regional/pdf/lapi2006/lapi2006.pdf. Accessed January 8, 2009.

Bureau of Economic Analysis. *Regional Economic Accounts: Regional Definitions.* Washington, DC, 2008b. http://www.bea.gov/regional/definitions/. Accessed January 8, 2009.

Bureau of Economic Analysis. *Table SA25N - Total full-time and part-time employment by NAICS industry (Virginia, 2005).* 2008c. http://www.bea.gov/regional/spi/action.cfm. Accessed January 16, 2009.

Bureau of Labor Statistics. *Current Employment Statistics (CES) Scope*. Washington, DC, 2007. http://www.bls.gov/ces/cescope.htm#3. Accessed January 8, 2009.

California Planning Roundtable. *Deconstructing Jobs-Housing Balance.* 2008. http://www.cproundtable.org/media/uploads/pub_files/CPR-Jobs-Housing.pdf. Accessed January 8, 2009.

Evans, M. Understanding the Different Employment Measures, Wyoming Department of Employment, Research & Planning, Casper, 1998. http://doe.state.wy.us/lmi/0498/0498a1.htm. Accessed June 26, 2009.

King County Budget Office. *King County Benchmarks: Land Use 2004.* Seattle, WA, 2004. http://www.metrokc.gov/budget/benchmrk/bench04/landuse/LandUse04.pdf. Accessed January 8, 2009.

NPA Data Services, Inc. 2007 Regional Economic Projection Series: Economic, Household, & Demographic Totals, 1969-2030, State Service Virginia. CD. Alexandria, VA, 2008.

Singa, K., Hutabarat, R., and Chou, M. Growth Visioning for the Westside Cities of Los Angeles County, California. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1895.* Transportation Research Board, Washington, DC, 2004, pp. 8-14.

U.S. Census Bureau. *Decennial Management Division Glossary*. Washington, DC, n.d.a. http://www.census.gov/dmd/www/glossary.html. Accessed January 7, 2009.

U.S. Census Bureau. *Virginia S2502. Demographic Characteristics for Occupied Housing Units (2005 American Community Survey).* Washington, DC, n.d.b. http://factfinder.census.gov/servlet/STTable?_bm=y&-context=st&-qr_name=ACS_2005_EST_G00_S2502&-ds_name=ACS_2005_EST_G00_&-CONTEXT=st&-tree_id=305&-redoLog=false&-geo_id=04000US51&-format=&-_lang=en. Accessed June 26, 2009.

U.S. Census Bureau. *Table 1: Annual Estimates of Housing Units for the United States and States: April 1, 2000 to July 1, 2005 (HU-EST2005-01).* Washington, DC, August 21, 2006. http://www.census.gov/popest/housing/tables/HU-EST2005-01.xls. Accessed June 26, 2009.

U.S. Census Bureau, Population Division. *Table 1: Annual Estimates of Housing Units for the United States and States: April 1, 2000 to July 1, 2007 (HU-EST2007-01).* August 21, 2008. http://www.census.gov/popest/housing/tables/HU-EST2007-01.xls. Accessed January 7, 2009.

U.S. Department of Transportation. Travel Model Improvement Program: Travel Model Discussions, Technical Synthesis Topic-Archive, Employment Data. Washington, DC, 2008. http://tmip.fhwa.dot.gov/discussions/technical_synthesis/archive/2008/february.stm. Accessed January 5-7, 2009.

APPENDIX B

DOES THE POPULATION OF A PLANNING DISTRICT COMMISSION PREDICT ITS SHARE OF DAILY VEHICLE MILES TRAVELED?

This report forecast daily vehicle miles traveled (DVMT) at the state level and then used the population of each planning district commission (PDC) to determine its share of DVMT. To test the accuracy of the assumption that DVMT is proportionate to population, Figure B1 compares the proportion of measured DVMT in each PDC (on the horizontal axis) to the proportion of population attributed to each PDC (on the vertical axis). If DVMT were perfectly proportional to population, a horizontal line would result. Instead, there is some discrepancy; for example, four PDCs—George Washington, Hampton Roads, Northern Virginia, and Richmond Regional— had 59.8% of the statewide measured DVMT and 64.2% of the statewide population. (This comparison has two known imperfections. First, the total DVMT in towns, which represents approximately 4% of the total DVMT, had to be estimated on the basis of other DVMT rather than directly measured. Second, and of less significance, there is a 0.002% difference [two one thousandths of 1 percent] between two estimates of total Virginia 2006 DVMT [VDOT, 2007; Schinkel, 2008]. Differences can arise due to rounding, and the latter value was chosen because it has been used by FHWA and thus adopted by VDOT as an official estimate [Schinkel, 2008]. As a consequence, this discrepant DVMT was distributed to PDCs on the basis of other DVMT.)

The Lenowisco PDC may be considered as an example. It was assumed that this PDC would have 1.22% of the state's DVMT since it has 1.22% of the state's population (see the vertical axis of Figure B1). Instead, it has 1.05% of the state's DVMT as measured from traffic counts (see the horizontal axis of Figure B1). In year 2035, this discrepancy will be about 0.54 million DVMT. The difference between the high DVMT growth and low DVMT growth projected for this PDC (see Table 5) is larger at 1.3 million DVMT. The error added by the population-based simplification of Eq. 6 does not mask the impact of the scenarios studied.

During a presentation of similar results to the VTrans2035 Multimodal Advisory Committee on October 14, 2008, it was noted that inclusion of transit with DVMT might eliminate some of the discrepancy shown in Figure B1. Because transit demand was measured as the number of unlinked passenger trips whereas auto demand (private vehicular travel) was measured as the number of DVMT, auto and transit demand are not immediately comparable. However, it is possible to convert transit trips to DVMT under the assumption that one transit passenger mile traveled (PMT) is equivalent to one auto VMT. Although the relationship between transit trips and transit PMT will vary by transit type and transit system, a weighted average based on sampling four bus systems using 2006 data (WMATA in Northern Virginia, Greater Richmond Transit in Richmond, Blacksburg Transit, and Lynchburg Transit) suggests that each transit trip accounts for 3.08 PMT and that each heavy rail trip accounts for 5.74 PMT (Federal Transit Administration, 2008b).

Data from the Virginia Department of Rail and Public Transportation (Hill, 2008) give transit trips for FY 2005 and FY 2006 by transit agency. Transit trips for calendar year 2006 were

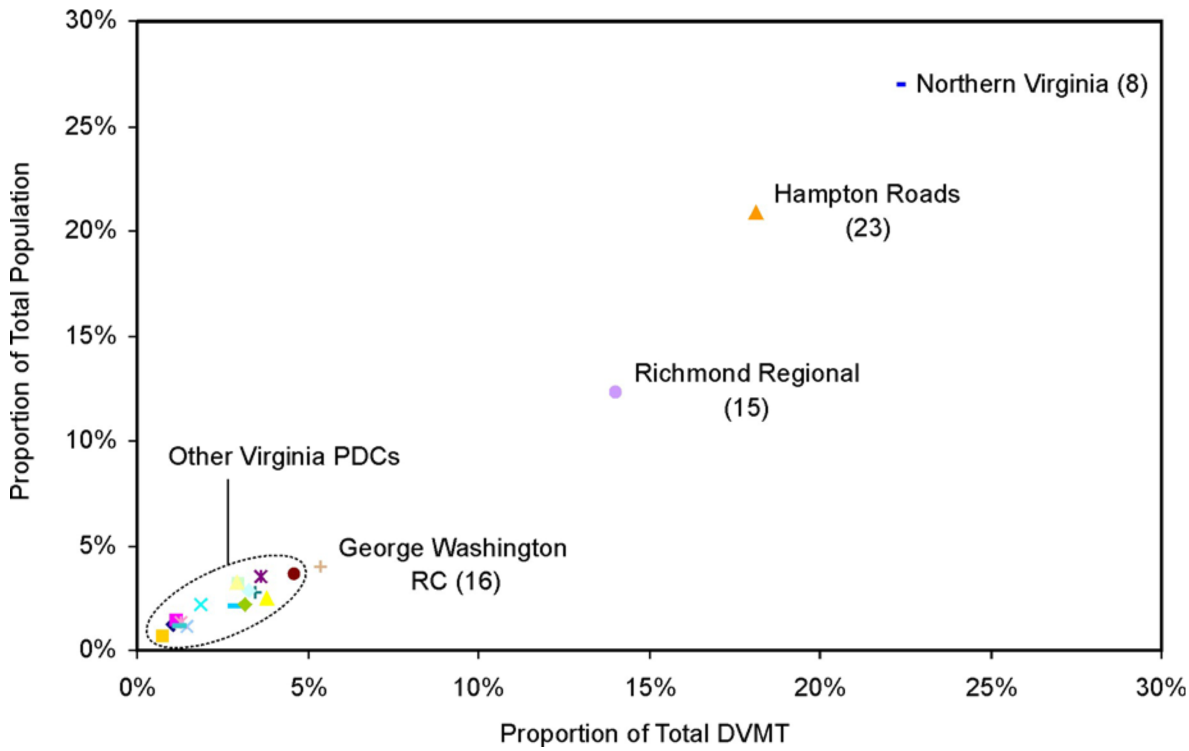

Figure B1. Proportion of Statewide Population vs. Proportion of Statewide DVMT for year 2006. Based on data obtained from Schinkel (2008), VDOT (2007), and Weldon Cooper Center for Public Service (2008).

estimated by averaging the FY 2006 (i.e., July 1, 2005, through June 30, 2006) and FY 2007 (i.e., July 1, 2006, through June 30, 2007) values. Transit trips were assigned to modified PDCs on the basis of where the PDC was located, and literature was used as necessary to determine these locations (American Public Transportation Association, 2003). In cases where the transit service encompassed two PDCs, the transit ridership was split between those PDCs. The transit trips were converted to DVMT by multiplying each transit trip by 3.08, except for the case of WMATA heavy rail where each trip was multiplied by 5.74. For example, Bay Transit had 132,614 trips in FY 2006 and 137,149 trips in FY 2007, for an average of 134,882 trips in calendar year 2006. Bay Transit serves the counties of Essex, Gloucester, King and Queen, King William, Mathews, and Middlesex (in PDC 18, the Middle Peninsula) as well as the counties of Lancaster, Northumberland, Richmond, and Westmoreland (in PDC 17, Northern Neck). Thus each of these PDCs is given ½ of 134,882 = 67,441 transit trips, which is equivalent to (67,441)(3.08) = 207,718 PMT. These annual PMT are then divided by 365 to convert to them to a daily estimate of PMT.

When the PMT from the transit calculations are added to the auto DVMT, Figure B1 changes slightly to Figure B2. For example, Northern Virginia still had 27% of the state's population, and its travel share increased from 22.3% (of the state DVMT) to 22.8% (of the state's combined PMT and DVMT). The four PDCs of George Washington, Hampton Roads, Northern Virginia, and Richmond Regional, which had 64.2% of the statewide population, saw their travel share increase from 59.8% (of the state DVMT) to 60.2% (of the state's combined PMT and DVMT).

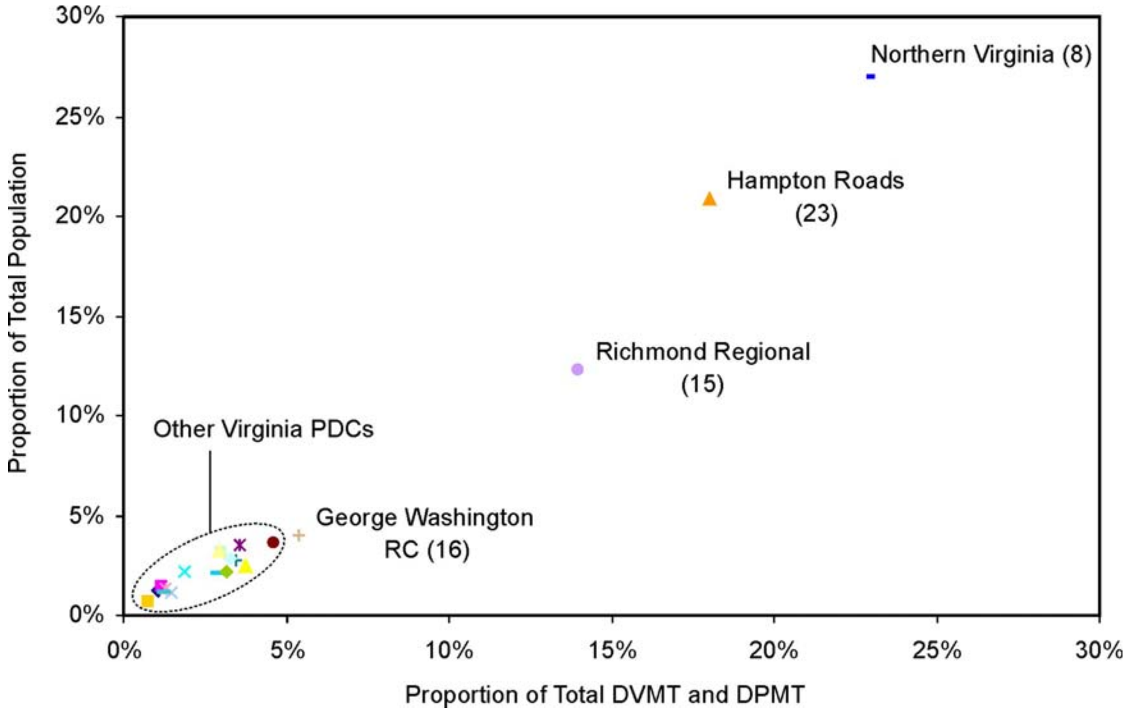

Figure B2. Proportion of Statewide Population vs. Proportion of Statewide DVMT and DPMT in 2006. Based on data obtained from Department of Rail and Public Transportation (Hill, 2008); Federal Transit Association (2008b); Schinkel (2008); VDOT (2007); and Weldon Cooper Center for Public Service (2008).

References

American Public Transportation Association. Virginia Transit Links. Washington, DC, 2003. http://www.apta.com/links/state_local/va.cfm. Accessed November 4, 2008.

Federal Transit Administration. National Transit Database: *TS2.1: Service Data and Operating Expenses Time-Series by Mode*. Washington, DC, 2008b. http://www.ntdprogram.gov/ntdprogram/data.htm. Accessed August 28, 2008.

Hill, C.T. Email to John Miller, October 17, 2008.

Schinkel, T.O. Email to John Miller. November 13, 2008.

Virginia Department of Transportation. 2006 Traffic Data: DVMT by Physical Jurisdiction. Richmond, 2007. http://www.virginiadot.org/info/resources/VMTReport_1200_2006.xls. Accessed August 22, 2008.

Weldon Cooper Center for Public Service, Demographics & Workforce Section. Population Estimates for Virginia, Localities, Planning Districts, & Metropolitan Areas: Final 2006 & Provisional 2007. Charlottesville, VA, 2008. http://www.coopercenter.org/demographics/sitefiles/documents/excel/populationestimates/2007_va_population_estimates.xls. Accessed June 16, 2008.

APPENDIX C

ANNUAL VEHICLE MILES TRAVELED (AVMT) REDUCTIONS ATTRIBUTABLE TO INCREASED DENSITY

Table C1. Summary of How Modifying Density May Affect Annual Vehicle Miles Traveled (AVMT) Reductions in Four Planning District Commissions (PDCs)

Modified PDC (PDC No.)[a]	Jurisdictions	2035 Population Base Case	2035 Population Increased Density	% Difference in Population	Difference in AVMT (millions)
George Washington RC (16)	Caroline County	36,967	28,030	24%	94
	King George County	35,861	23,830	34%	127
	Spotsylvania County and Fredericksburg City	299,150	304,479	2%	–52
	Stafford County	266,320	281,959	6%	215
	Total	638,298	638,298	[b]0%, 7%	384
Northern Virginia Regional Commission (8)	Arlington County and Alexandria City[c]	401,171	650,380	62%	–34
	Fairfax County, Fairfax City, and Falls Church City	1,615,394	2,050,129	27%	–3,403
	Loudoun County	694,305	325,570	53%	2,694
	Prince William County, Manassas City, and Manassas Park City	773,828	458,620	41%	2,666
	Total	3,484,698	3,484,698	[b]0%, 39%	1,924
Richmond Regional (15)	Charles City County	8,377	7,270	13%	12
	Chesterfield County	579,255	542,786	6%	308
	Goochland County	29,070	21,280	27%	82
	Hanover County	163,176	108,010	34%	452
	Henrico County and Richmond City	556,299	687,606	24%	–1,111
	New Kent County	29,335	18,640	36%	113
	Powhatan County	51,039	30,960	39%	212
	Total	1,416,551	1,416,551	[b]0%, 19%	69
Hampton Roads (23)	Isle of Wight County	46,686	36,350	22%	109
	James City County and Williamsburg City	113,127	77,660	31%	346
	Southampton County and Franklin City	28,004	26,340	6%	18
	York County, Hampton City, Newport News City, and Poquoson City	476,151	609,023	28%	–1,124
	Chesapeake City, Norfolk City, and Portsmouth City	600,538	549,630	8%	431
	Suffolk City	107,029	84,450	21%	153
	Virginia Beach City	689,071	677,153	2%	101
	Total	2,060,607	2,060,607	[b]0%, 13%	34
Total AVMT Reduction in the Four PDCs					2,411[d]

[a] PDC boundaries were modified as indicated in Table 1.

[b] The regional population is unchanged by the two scenarios; thus, the regional population percentage difference is zero. However, the individual jurisdiction populations differ. For example, for George Washington RC, the magnitude of these differences are 8,937 (Caroline, computed as 36,967 – 28,030); 12,031 (King George); 5,329

(Spotsylvania and Fredericksburg); and 15,639 (Stafford), for a total of 41,936, which is about 7% of the region's population of 638,298.

[c] One modification to the scenario to place only one fourth of Northern Virginia's new growth in the highest density jurisdiction (Alexandria plus Arlington)—and to place the remaining three fourths in the next highest density jurisdiction (Fairfax and Falls Church). The reason for this change is that placing one half of the growth in Arlington and Alexandria would yield a density of 23,358 people/mi^2 in 2035—which is technically possible but that would yield a density comparable to that of New York City at present. (If this were done, Northern Virginia alone would see a 10.04% reduction in AVMT, which translates to a savings of 11.06 million DVMT for Northern Virginia. Multiplying these 11.06 million DVMT by 365 days/year and 452.92 g / DVMT of CO_2 emissions yields about 1.83 million metric tons of CO_2 for Northern Virginia, a value higher than that shown in Table 10.)

[d] The 2,411 difference represents about 3.72% of the total AVMT for these four PDCs, based on population data projected from NPA Data Services, Inc. (2008). Had population data projected from the Virginia Employment Commission (2008) been used, the AVMT reduction would have been estimated to be 2,432, which is about 4.06% of the total AVMT under these scenarios.

References

NPA Data Services, Inc. 2007 Regional Economic Projection Series: Economic, Household, & Demographic Totals, 1969-2030, State Service Virginia. CD. Alexandria, VA, 2008.

Virginia Employment Commission. Download Center: Index of lmi/data/population. Richmond, May 20, 2008. http://www.alex.vec.state.va.us/lmi/data/population/popproj.xls. Accessed June 16, 2008.

APPENDIX D

ASSUMPTIONS FOR THE CASE STUDY IN POLICY RESPONSE 2 AND THE FEASIBILITY OF COMPARING ALTERNATIVES

Assumptions for Computing Costs and Benefits

Comparison of the seven alternatives for the scenario in the case study for Policy Response 2 requires several assumptions regarding the costs and benefits of each alternative. These assumptions are noted here and may vary from one specific situation to the next.

- There are 250 commuting days per year. During those commuting days, there is a total of 5 peak hours, with 10% of the DVMT occurring during each of those peak hours. Thus, one half of the vehicle miles traveled (VMT) occurs during these 5 peak hours and the other one half occurs under uncongested conditions.

- All capital investments have a service life of 20 years, and an annualized cost is determined based on this 20-year service life and a discount rate of 4%.

- National data sources, such as the Environmental Protection Agency (2007) for estimating emissions, Sinha and Labi (2005) for estimating costs, and Evans (2004) for determining transit elasticity, are appropriate.

- Alternative 1 (support transit-oriented demand [TOD]) assumes that the agency cost is the capital cost of providing bridges and lighting to make an area where existing transit service is available more suitable for residential development, as was noted elsewhere (Cottrell, 2007). Under this alternative, eventually some persons who presently drive along this arterial might choose to live in the area made accessible to transit and use transit.

- Alternative 2 (increase bus service) and Alternative 3 (reduce fares) assume that 1 vehicle hour is required for each bus, at a cost of $108.67 (in 2007 dollars). With 20 passengers per bus and a $2 fare, the agency cost per rider is $3.43.

- Alternative 4 (parking subsidy for carpoolers) assumes that the agency pays for parking ($10/day shared among three carpoolers) and that 1,000 of the 3,000 auto drivers are given an opportunity to participate in the subsidy program. (As with the preceding alternatives, not all who are given the opportunity choose to participate.)

- Alternative 5 (construction of an HOV/HOT lane allowing trucks) assumes that the extra lane is reversible based on peak flow, will increase speeds on that lane from 20 to between 30 and 40 mph, and that one half of the cost will be covered by toll-paying users.

- Alternative 6 (construction of an HOV/HOT lane prohibiting trucks) assumes that the loss of trucks means that only 35%, rather than 50%, of the cost will be covered by tolls.

- Alternative 7 (construct frontage roads) assumes that 8 lane miles (4 miles in each direction) are constructed for businesses, thereby eliminating most access points on the arterial, which may increase speeds by between 5 and 10 mph.

Feasibility of Comparing Alternatives

The seven alternatives differ in fundamental ways, which precludes a decision based solely on cost-effectiveness of emissions reduction.

- The transit-based alternatives are scaleable: they can implemented for a short period of time (e.g., a peak hour or just a few years), whereas the infrastructure investments can be purchased only in long-term (usually 20 year) increments.

- The proportion of costs paid by the agency relative to users varies by alternative: the agency pays the full cost for the access management alternative, whereas users pay a substantial portion of the cost for the HOT lane alternative.

- Some alternatives have benefits during off-peak periods, such as the access management alternative, which reduces arterial access points.

- The agency generally has full authority (although not necessarily the resources) to implement the transit-based alternatives but not the encouragement of TOD, which relies on a willing private sector participant.

Thus, because the alternatives have different levels of risk, there are reasons in addition to cost-effectiveness to consider their implementation. That said, a cost-effectiveness comparison for a given situation has merit to the extent that limited resources force the Commonwealth to consider carefully just one goal, or a limited number of goals, and the ability of an alternative to achieve that goal.

References

Cottrell, W.D. Transforming a Bus Station into a Transit-Oriented Development: Improving Pedestrian, Bicycling, and Transit Connections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2006.* Washington, DC, 2006, pp. 114-121.

Environmental Protection Agency. *MOBILE6 Vehicle Emission Modeling Software.* Washington, DC, 2007. Accessed November 24, 2008.

Evans, J.E., IV. *Transit Scheduling and Frequency: Traveler Response to Transportation System Changes*. TCRP Report 95 (Chapter 9). Transportation Research Board, Washington, DC, 2004.

Sinha, K.C., and Labi, S. *Transportation Decision Making.* John Wiley & Sons, Inc., Hoboken, NJ, 2007.