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A Retrospective Evaluation of Traffic Forecasting Techniques

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JOHN S. MILLER, Ph.D., P.E.
Principal Research Scientist

SALWA ANAM
Graduate Research Assistant

JASMINE W. AMANIN, MUEP
Engineering Technician

RALEIGH A. MATTEO
Research Assistant

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530 Edgemont Road, Charlottesville, VA 22903-2454
www.VTRC.net

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Traffic forecasting techniques—such as extrapolation of previous years' traffic volumes, regional travel demand models, or local trip generation rates—help planners determine needed transportation improvements. Thus, knowing the accuracy of these techniques can help analysts better consider the range of transportation investments for a given location. To determine this accuracy, the forecasts from 39 Virginia studies (published from 1967-2010) were compared to observed volumes for the forecast year. Excluding statewide forecasts, the number of segments in each study ranged from 1 to 240. For each segment, the difference between the forecast volume and the observed volume divided by the observed volume gives a percent error such that a segment with a perfect forecast has an error of 0%. For the 39 studies, the median absolute percent error ranged from 1% to 134%, with an average value of 40%. Slightly more than one-fourth of the error was explained by three factors: the method used to develop the forecast, the length of the duration between the base year and forecast year, and the number of economic recessions between the base year and forecast year. In addition, although data are more limited, studies that forecast a 24-hour volume had a smaller percent error than studies that forecast a peak hour volume ($p = 0.04$); the reason is that the latter type of forecast requires an additional data element—the peak hour factor—that itself must be forecast. A limitation of this research is that although replication of observed volumes is sought when making a forecast, the observed volumes themselves are not without error; for example, an "observed" traffic count for a given year may in fact be based on a 48-hour count that has been expanded, based on seasonal adjustment factors, to estimate a yearly average traffic volume.

The primary recommendation of this study is that forecasts be presented as a range. For example, based on the 39 studies evaluated, for a study that provides forecasts for multiple links, one would expect the median percent error to be approximately 40%. To be clear, detailed analysis of one study suggests it is possible that even a forecast error will not necessarily alter the decision one would make based on the forecast. Accordingly, considering how a change in a traffic forecast volume (by the expected error) influences decisions can help one better understand the need for a given transportation improvement. A secondary recommendation is to clarify how some of these traffic forecasting techniques can be performed, and supporting details for this clarification are given in Appendix A of this report.

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FINAL REPORT

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John S. Miller, Ph.D., P.E.
Principal Research Scientist

Salwa Anam
Graduate Research Assistant

Jasmine W. Amanin, MUEP
Engineering Technician

Raleigh A. Matteo
Research Assistant

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EXECUTIVE SUMMARY

Traffic forecasting techniques—such as extrapolation of previous years' traffic volumes, regional travel demand models (TDMs), and local trip generation rates—help planners determine needed transportation improvements. The Virginia Department of Transportation's (VDOT's) Transportation and Mobility Planning Division commissioned the development of a *Traffic Forecasting Guidebook* (hereinafter the *Guidebook*) to present such techniques. At the time this study began, the *Guidebook* was in draft form and was expected to be revised to address comments by VDOT staff.

In this context, this study was conducted in response to a request from VDOT's Transportation and Mobility Planning Division to determine the accuracy of forecasts from past Virginia studies; compare particular forecasting techniques in terms of accuracy, data requirements, and assumptions; identify causal factors that might explain differences in forecast accuracy; and determine how the findings of this study should influence the guidance given in a future revision of the *Guidebook.*

A traffic forecasting technique is a replicable procedure for forecasting a traffic volume for some future year. Examples of techniques included in the *Guidebook* are extrapolating previous years' traffic volumes, adjusting outputs from regional TDMs, using the Fratar method, and using trip generation rates from the Institute of Transportation Engineers (ITE) for specific land uses. Nine techniques identified by the research team in the *Guidebook*, in addition to two other techniques not in the *Guidebook,* can be used by planners for short-term forecasts (such as those required to conduct a land development study for a parcel that will be developed within a couple of years) and longer term forecasts (such as those required to examine the needs of a corridor two decades in the future).

To determine the accuracy of forecasts, a review of 39 Virginia studies, such as corridor studies, land development studies, regional TDMs, and technical memoranda published from 1967-2010 such that the forecast year had elapsed, was used to compare forecast and observed volumes as requested. In theory, this comparison would be a simple data collection exercise: How close were forecasts to observed volumes? In practice, the comparison was untidy for several reasons including the following:

- Expected highway improvements at the time forecasts were made may not have transpired.
- Observed volumes were not collected at the same level of detail as forecast volumes.
- Roadway alignments may have changed such that how to align forecast and observed volumes is not always clear.
- Forecast methods may have changed such that one might argue that insights from older studies are no longer relevant.

- There may be seasonal variation in traffic volumes such that a special count collected for a study differed from a true yearly average traffic volume.

Accordingly, the process for deciding how to compare forecast and observed volumes for each of the 39 studies necessitated some assumptions by the research team, and these are noted in Appendix B.

Excluding those for statewide forecasts, the number of segments in each study where a volume could be forecast ranged from 1 to 240. For each segment, the difference between the forecast and observed volume divided by the observed volume gives a percent error, such that a segment with a perfect forecast has an error of 0% and a segment where the forecast is 3 times the observed volume has an error of 200%. For each study, therefore, *median absolute percent error* was tabulated, which ranged from 1% to 134%. For the 39 studies, this error averaged 40%. If the word "absolute" is removed to give the term *median percent error* such that a link overforecast cancels a link underforecast, the tabulation yields a lower value for each study, and the average of this value for the 39 studies was 31%. Because a study may have a few links with very large errors, use of the *mean* rather than the *median* gives a higher error value: for the 39 studies, the average of the *mean absolute percent error* was 55%. Excluding the 6 studies that forecast a peak hour volume, the 33 remaining studies that forecast a 24-hour volume had, on average, a *median absolute error* of about 6,000 vehicles per day.

Factors initially believed by the research team to affect the magnitude of the forecast error included the forecast type (e.g., peak hour volume versus a 24-hour volume), the forecast method, the duration (time elapsed between base year and forecast year), and the number of recessions between the base year and the forecast year. The forecast type had a statistically significant impact (e.g., a p-value of 0.05 or less): for the few cases where both the average daily traffic and a peak hour volume were forecast, the median absolute percent error of the former was significantly lower than that of the latter ($p = 0.04$). This difference appeared to be attributable to the fact that unlike the average daily traffic, the forecast of the peak hour volume requires the K-factor, which itself must be forecast. An analysis of variance further showed that three statistically significant factors explained about 29% of the variation in median percent error: the forecast method, the duration, and the number of recessions. That is, although these factors were statistically significant ($p < 0.05$), additional factors not uncovered by this study help explain differences between forecast and observed volumes.

Whether a forecast error is large or small, a related question is: Does the error matter? A detailed analysis of one study showed that whether a forecast error affects the actions taken depends in part on the magnitude of the error—as one might expect—but also on the location of the error relative to the decision criteria. For instance, in that study (Study 1, as described in the body of this report), the decision criterion was whether a certain performance standard—in this case, Level of Service C—could be obtained. Although a 61% forecast error was noted (e.g., the forecast value exceeded the observed value by 61% for this single link), this error would not have affected the decision that the roadway needed to be improved because both the forecast volume and the observed volume would have indicated that Level of Service C was not attained.

The current study has two recommendations for revisions to the *Guidebook,* one concerning how forecasts are presented and one concerning how forecasts are performed.

1. *When making forecasts for traffic volumes, analysts should include some indication of expected forecast error and present forecasts as a range.* This recommendation is based on the findings of this study regarding the comparison between forecast and observed volumes, Specifically, a certain amount of error has been observed based on differences between forecast and observed volumes, the identifiable factors explained only a portion of this error, and the magnitude of the error alone does not determine whether the error is important. The amount of the forecast error indicated could be what was reported in this study (e.g., a median absolute percent error of 40%), or it could be based on other sources if so desired. Such an indication of expected forecast error is not unique to Virginia: a survey of planners reported in CDM Smith et al. (2014) suggested that on a link-by-link basis, planners would expect an error of ±42.5% for a forecast of the volume of an existing facility for 20 years in the future. With this information, analysts can examine whether a forecast (with the expected error) materially affects actions being taken on the basis of the forecast. (For example, one study examined by the research team noted that a certain investment remained "economically feasible" even with a forecast error of 50%.)

2. *A few clarifications should be made in the explanation of three of the techniques:* Technique 5 (regarding how seasonal adjustment factors are used based on VDOT's data sets); Technique 7 (regarding how ESALs are computed and how to take advantage of updated guidance from VDOT's Materials Division); and Technique 8 (to take advantage of a spreadsheet for applying the Fratar method). Details of how to apply these techniques are given in Appendix A.

FINAL REPORT

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John S. Miller, Ph.D., P.E.
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Salwa Anam
Graduate Research Assistant

Jasmine W. Amanin, MUEP
Engineering Technician II

Raleigh A. Matteo
Research Assistant

INTRODUCTION

The Virginia Department of Transportation (VDOT) is responsible for forecasting project-level, corridor-level, regional level, and statewide-level traffic volumes. Respective Virginia examples of such forecasts include those for a mixed used retail and residential development at the northwest quadrant of a primary and secondary road (Stonefield in Albemarle County); those for an almost 90-mile Route 3 corridor (from King George to Matthews County); those for a regional travel demand model (TDM) for the Hampton Roads metropolitan area; and traffic forecasts available through the Statewide Highway Planning System, known as "SHiPS" (VDOT, 2005b). The amount of detail for these studies can vary greatly, from a few pages in a file that indicate projected volumes at a relocated intersection (as was the case with the Bell Creek Road intersection improvements in Hanover County) to a 50-page traffic impact assessment (for a wholesale club and gas station in Henrico County).

A traffic forecasting technique is a replicable procedure for generating a traffic volume for some future year. These forecast volumes can take several forms.

- *Forecasts can vary by time period*. Forecasts may refer to a 24-hour volume, often referred to as vehicles per day (vpd), which may mean either average daily traffic (ADT) or average weekday traffic (AWT). Such volumes may also include the word "annual" as in average annual daily traffic (AADT); in theory, the difference between ADT and AADT is that the latter is based on a continuous count over a 1-year period (Garber and Hoel, 1998) rather than a periodic count that has been adjusted to reflect an annual average. For consistency, this study uses the terms "ADT" and "AWT." Alternatively, these volumes may also reflect travel during a peak hour of the 24-hour period, which may be the 30th highest hourly volume if the site is a continuous count station (Jones, 2014); the portion of ADT occurring during the peak hour, which is ADT multiplied by the K-factor (Texas Department of Transportation, 2014); or a percent of ADT chosen by the designer, with typical values of 12% to 18% for rural highways and 8% to12% for urban highways (Garber and Hoel, 2015). This volume can be referred to as the "peak hour" or "design hour" (VDOT, 2005a); for consistency, this study used the term "peak hour volume."

- *Forecasts can vary by vehicle type*. Forecasts may reflect all vehicles where a truck, car, or motorcycle carries equal weight, or they may reflect a certain class of vehicles, as is the case with average daily truck traffic (ADTT). Forecasts may also aggregate vehicle classes as in the case of equivalent single-axle loads (ESALs) for pavement design where a tractor trailer is the equivalent of more than 5,000 passenger cars.

- *Forecasts can reflect volumes at either an intersection or a link*. An example of the former is 543 northbound vehicles on Route 29 turning left onto Route 649 eastbound during the morning peak hour at the University of Virginia Research Park. An example of the latter is 235,000 ADT between Braddock Road and Route 236 on I-495.

- *Forecasts can refer to infrastructure that may or may not currently exist.* Forecasts can refer to an existing roadway segment whose geometry will not be changed in the future; a segment that will be widened, narrowed, or otherwise altered in some fashion; or a segment that has not yet been built.

- *Forecasts can be short range or long range.* The difference between the base and forecast year may be as short as 2 years (as was the case with the aforementioned Stonefield where a 2011 forecast reflected a development where counts were available in 2013) or as long as 30 years (as was the case with the Hampton Roads TDM Study, which had a 2000 base year, a 2011 interim forecast year, and a forecast year of 2030).

- *Forecasts can be large or small.* Because forecasts can vary by time period or facility type, they can differ by several orders of magnitude. For instance, the Federal Highway Administration (2000) reported eight classifications (interstates, arterials, collectors, and locals, with each of them having rural and urban subclassifications). A 2011 forecast ADT of Town Point Road, a 0.1- mile urban minor arterial in Hampton Roads, was 6,955; the 2011 forecast ADT for Court Street, a collector road of similar length, was 324.

- *Forecasts support a variety of purposes.* Travel forecasts support a diversity of planning-related deliverables: examples include a corridor study that examines alternatives for improving mobility; traffic impact analyses that quantify the congestion that may result from developing a given parcel of land; a bridge sufficiency study that determines the extent to which heavy vehicles must be accommodated; an intersection study that will examine the suitability of different types of traffic control; an evaluation of environmental impacts for various alternatives; and a safety study that may examine how retiming signals can help accommodate pedestrians. For example, the Capital Beltway Study (JHK & Associates et al., 1989) evaluated how widening improvements would affect level of service (LOS); the University of Virginia Research Park Traffic Impact Analysis Study (The Cox Company, 2008) evaluated how access improvements (e.g., signals and turn lanes) would affect peak hour delay at intersections; the U.S. 15 James Madison Highway Passing Lane Study (UMA Engineering, Inc., 1997), as its name suggests, determined where passing lanes should be added; and the Richmond

International Airport Corridor Feasibility Study (The LPA Group and David Volkert & Associates, 1999) evaluated alternative interchange designs and widenings for providing highway access to the airport, considering safety, congestion, and takings of wetlands.

VDOT's Transportation and Mobility Planning Division (TMPD) commissioned the development of a *Traffic Forecasting Guidebook* (hereinafter the *Guidebook*) to present techniques for generating traffic volume forecasts. At the time this study began, the *Guidebook*, which was being developed by a consulting firm, was in draft form and showed comments provided by VDOT staff that would be addressed by the firm writing the *Guidebook* at some point in the future. The *Guidebook* includes several techniques for generating traffic forecasts that reflect the diversity of the types of forecasts noted previously. These techniques may also be combined.

Although the *Guidebook* has headings that enumerate 11 techniques, the opinion of the research team was that 1 of the techniques, i.e., traffic count trend analysis, should be subdivided into 2 techniques (shown as Techniques 3 and 4 in Table 1) because the 2 techniques use two different mathematical approaches. The research team also thought that 2 other techniques listed in the *Guidebook* (i.e., diurnal development and peak hour link forecasting) should be combined because the reason for performing the former technique is to obtain a K-factor that is then used to apply the latter technique. Accordingly, these 2 techniques are represented as Technique 6 in Table 1. Thus, based on the 11 techniques that can be gleaned from the *Guidebook*, 2 techniques were excluded: the intersection forecasts –simple-growth technique, and the VDOT 527 process. (The simple-growth technique was excluded because based on the research team's review of the *Guidebook*, it is inferior to the Fratar method. The VDOT 527 process was excluded because it involves newer forecasting approaches, such as the MXD method, which were under study at the time this research was undertaken (Virginia Transportation Research Council, 2013). Two additional techniques were identified by the research team during the course of this study and were added to Table 1: the traffic shift method for corridors (Martin and McGuckin, 1998), which is shown as Technique 11, and population-based forecasts (VDOT, 1988a), which is shown as Technique 9. Examples of how to apply the techniques in Table 1 are given in Appendix A.

This study was conducted in response to a request from VDOT's TMPD to determine the accuracy of forecasts from past Virginia studies; compare these forecasting techniques in terms of accuracy, data requirements, and assumptions; identify causal factors that may explain differences in forecast accuracy; and determine how the findings of this study should influence the guidance given in a future revision of the *Guidebook*.

Table 1. Summary of Techniques Extracted From the *Traffic Forecasting Guidebook* and Other Sources[a]

Technique No.	Name	Summary of Technique[b]
1 [c]	Adjusted regional model outputs	Use difference between modeled volume (in 1990) and actual volume (in 1990) to adjust the link forecast (in 2010).
2 [c]	Trend analysis of regional model outputs	Determine annual rate of growth from modeled volume (in 1990) and forecast volume (in 2010); apply to a 1990 volume in order to develop an interim link forecast for year 2000.
3 [c]	Linear growth based on two traffic counts	Determine annual rate of growth from actual volumes for 1980 and 1990; apply to 1990 volume to get a 2010 forecast.
4 [c]	Regression based on multiple traffic counts	Determine annual rate of growth from actual volumes for 1975, 1980, 1985, and 1990; apply to 1990 volume to get a 2010 forecast.
5 [c]	Seasonal adjustment factors	Multiply the 2010 annual forecast from Techniques 1, 2, 3, or 4 by the appropriate seasonal adjustment factor to obtain a daily forecast for a given day of the week and month of the year.
6 [c]	Peak hour link forecasting	Multiply the 2010 ADT (average daily traffic) from Techniques 1, 2, 3, or 4 by the K-factor calculated from continuous count stations to forecast the 2010 peak hour volume.
7 [c]	ESAL (equivalent single-axle load) estimation	Adjust the 2010 annual forecast (Techniques 1, 2, 3, or 4) by factors from VDOT's Materials Division (VDOT, 2014b) to estimate 2010 ESALs for a given link.
8 [c]	Fratar method	Use current intersection movements (e.g., left, right, and through movements on each of 4 legs in 1990), coupled with 1990 and 2010 link volumes (e.g., 2 directional volumes on each of 4 legs) to estimate 2010 turning movements iteratively (left, right, and through) on each approach.
9 [d]	Population-based forecasts	Multiply the 1990 ADT by the ratio of the forecast 2010 population to the actual 1990 population to forecast a 2010 ADT.
10 [c]	ITE-based factoring	Forecast 2010 trips based on land use as noted in the Institute of Transportation Engineers (ITE) *Trip Generation Manual* (2012) and then reduce these trips based on mixed land uses if appropriate as noted in the ITE (ITE, 2004).
11 [d]	Traffic shift method for corridors	Based on Martin and McGuckin (1998) and an increase in volume (and hence a decrease in travel time) for a given roadway segment, calculate the expected change in volume for a parallel roadway segment.

[a] One technique that is not shown is the newer MXD method (referred to in the *Guidebook* under the "Chapter 527 Process." This technique, along with others that are viewed as an alternative to Technique 10, is the subject of a separate research effort (Virginia Transportation Research Council, 2013) and is not discussed here.
[b] All techniques presume a base year of 1990 and a horizon year of 2010.
[c] Technique was identified by the research team in the *Traffic Forecasting Guidebook.*
[d] Technique was identified by the research team in a source other than the *Traffic Forecasting Guidebook.*

PURPOSE AND SCOPE

The purpose of this study was to respond to a request from VDOT's TMPD to determine, based on an examination of previous Virginia studies, the accuracy (and associated causal factors), data requirements, and inherent assumptions regarding the 11 traffic forecasting techniques listed in Table 1.

Specifically, the objectives of the study were as follows:

1. Determine the accuracy of forecasts from past Virginia studies.

2. Identify assumptions inherent in applying the forecast techniques.

3. Compare the 11 forecasting techniques listed in Table 1 in terms of data requirements.

4. Identify causal factors that may explain differences in forecast accuracy.

5. Determine how the findings of this study should influence the guidance given in a future revision of the *Guidebook*.

The scope of the study was limited to techniques for which appropriate Virginia historical data were available.

METHODS

To achieve the study objectives, forecast volumes from previous traffic forecasts reported in the Virginia studies listed in Table 2 were compared to observed volumes, with the details of this approach guided by feedback from the study's technical review panel (TRP) provided through two meetings, one on March 27, 2015, and the other on February 17, 2016.

Seven tasks were conducted to carry out the methods for the study:

1. Collect Virginia studies in which traffic forecasts were made.

2. Collect data that would allow the application of other forecasting techniques.

3. Collect observed traffic volumes for the Virginia studies.

4. Document inherent assumptions in the Virginia studies.

5. Apply techniques from the *Guidebook* to the Virginia studies.

6. Report the accuracy of traffic forecasts in the Virginia studies and compare with accuracy reported in the literature.

7. Determine the impacts of explanatory factors on forecast accuracy.

Collect Virginia Studies in Which Traffic Forecasts Were Made

Initially, the research team sought to obtain studies for which traffic forecasts had been generated. Accordingly, the goals and expected methods of this study were presented to VDOT district planners on February 27 and May 22, 2014. (It is not known for certain which districts were represented at the meetings; however, planners from all nine VDOT construction districts] were invited to attend the meetings.) At the end of each presentation, district planners were asked to indicate if any studies were available, with the criterion that the forecast year had elapsed. Positive responses led to one or more members of the research team visiting VDOT's Culpeper, Hampton Roads, and Richmond districts and VDOT's TMPD on April 16, July 1, September 16, September 18, and December 23, 2014.

Studies were also obtained through follow-up communications with VDOT district and TMPD staff and a visit to the VDOT Research Library. For example, during a presentation to the TRP on March 27, 2015, attendees suggested that the research team examine VDOT's LandTrack database for additional historical studies.

A total of 40 Virginia studies for which traffic forecasts had been generated were thus obtained, including regional travel demand forecasting models, corridor studies, site impact studies, and statewide regional planning studies. These studies are listed in Table 2.

Collect Data That Would Allow Application of Other Forecasting Techniques

A review of the studies obtained in Task 1 showed that not all techniques given in the *Guidebook* had been applied in the past. For example, although Technique 3 (linear growth based on two traffic counts) had been applied frequently, Technique 8 (Fratar method) had not been applied in any study. Accordingly, data sources that would allow the research team to apply such techniques were sought. For example, Agnello (2015) suggested that intersection counts would be available in Northern Virginia, which led to communications with staff of VDOT's Northern Virginia District (Azimi, 2015a, b, c). The research team thus obtained data from an intersection count that had been repeated several years later. This enabled the research team to apply Technique 8 (Fratar method) at an intersection. Thus this study was added to the 40 shown in Table 2 to make 41 studies. As another example, the research team obtained seasonal adjustment factors from an internal application provided by Jones (2014), which allowed the research team to apply Technique 5 (seasonal adjustments), as described in Appendix A.

Collect Observed Traffic Volumes for the Virginia Studies

There were at least five sources to obtain observed traffic volumes against which the accuracy of the forecasts in the Virginia studies might be assessed.

1. *The annual electronic VDOT traffic data publications.* These publications (VDOT, 2014a) were available to the public. They listed ADT and AWT for interstate,

primary, and secondary facilities for each year from 2001-2013 inclusive; ADT and AWT for interstate and primary facilities only for year 2000; and ADT only for interstate and primary facilities for years 1975, 1980, 1985, 1990, and 1995.

2. *The VDOT hardcopy traffic counts.* Annual ADT (but not AWT) for interstate and primary (but not secondary) facilities were available from the VDOT Research Library for the period from1960-1999, although in some cases they referred to a state fiscal year (July 1 to June 30) rather than a calendar year (for example, VDOT, 1961).

3. VDOT's Traffic Monitoring System (TMS) database (VDOT, undated a). This provides ADT by year (for the period from 1997-2013) and raw traffic count data.

4. *VDOT GIS shapefiles of traffic counts* (VDOT, 2014a). This source was used explicitly for the Hampton Roads TDM Study (Study 22 in Table 2). Lee (2014) provided a GIS shapefile of traffic counts, which had ADT and AWT counts for the years 1997-2013 inclusive.

5. *SHiPs data tables.* This source was used exclusively for evaluating the SHiPS forecasts (Study 25 in Table 2). A table in this database named SHiPS_TBL_PLANNING_DATA listed an actual ADT for each link (VDOT, 2015). (SHiPS was accessed on April 6, 2015, through an internal server configured by VDOT to provide data through the Microsoft Access software package [VDOT, 2015].) When an observed peak hour volume was needed, the approach used by the research team was to multiply the ADT by the K-factor as recommended by Jones (2015).

To be clear, the five sources originated from what the research team believes to be a common data source, i.e., Source 1, although there are variations in detail provided and availability.

Document Inherent Assumptions Made by the Research Team in the Virginia Studies

There were five types of general assumptions made by the research team that needed to be understood in order to compare forecasts and actual counts.

First, the difference in referencing systems between the roadway network used in the study and the roadway network that held observed counts needed to be understood. For example, in Study 1, a 2010 forecast was given for a Route 3 segment between Route 301 and Route 205 (VDOT, 1988a); however, this segment reflected two sub-segments (also known as sections or links) in the observed traffic counts (VDOT, 2011): a 7.18-mile section with a volume of 5,000 ADT and a 2.84-mile section with a volume of 4,600 ADT. Accordingly, a weighted volume of 4,887 was computed based on these two sub-segments (see Eq. 1).

$$\frac{7.18\text{ miles}}{7.18\text{ miles} + 2.84\text{ miles}}(5{,}000\text{ ADT}) + \frac{2.84\text{ miles}}{7.18\text{ miles} + 2.84\text{ miles}}(4{,}600\text{ ADT}) = 4{,}887 \quad \text{[Eq. 1]}$$

Second, links that could not be matched to locations in VDOT's TMS database (VDOT, undated a) or existing VDOT count locations were excluded. For example, in Study 20, of 64 links shown in the Route 29 Corridor Study, 47 were excluded because the start or end location of the link could not be determined. As another example, for Study 22, the Hampton Roads TDM Study required the merging of several different data sources into one application. In order to determine the best links for the study, an application was developed by the research team in ArcGIS using the Model builder tool supplemented with a script in Python. The application assigned a buffer to the roadway segment based on the number of lanes and the facility type and associated a roadway segment to the proper traffic counter. These links were manually verified by the research team using the TMS web application (VDOT, undated a). This resulted in 42 forecast links whose location and distance matched the TMS traffic counter locations exactly (VDOT, undated a). However, there were 163 links that had an imperfect match; those links (as well as links that had no match) were excluded from the analysis conducted by the research team.

Third, the item being forecast—such as a peak hour volume, a 24-hour volume, a turning movement, or a 24-hour weekday volume—was noted. If this could not be determined from the study documentation, additional inquiries were made, where possible, to make this determination and the uncertainty was noted. For example, for Study 22 (Hampton Roads TDM Study), it was not initially clear whether the forecast was for AWT or ADT. Additional inquiries suggested that the study was likely forecasting AWT, but the difference in error rates depending on whether AWT or ADT was used for the observed volume is reported in Appendix B. For an earlier study at the same location (Study 21), it appears AWT was forecast; however, for the forecast year of 1985, observed AWT was not available. Thus observed ADT was compared to forecast AWT.

Fourth, the extent to which the forecast depends on certain improvements was noted. For example, the Route 3 Corridor Study (VDOT, 1988a) provided a list of approximately 50 improvements, such as adding turn lanes, widening to four lanes, and improving shoulders, and the forecasts given are independent of these improvements. Logically, however, one would expect that the extent to which the improvements were made would affect the forecast. (For example, the study suggested that at a point where the road was signed as both Route 3 and Route 33, in the future Route 33 could be relocated and Route 3 could be widened from two to four lanes. However, this relocation and widening had not happened as of 2015.)

Fifth, the method that underlies the forecasts in each study was documented—but sometimes this method was not clear. For example, for Study 1 (VDOT, 1988a), the study noted that the forecasts are "based upon the historical traffic growth trends for the past twenty years." Accordingly, the method appears similar to what the *Guidebook* defined as a trend analysis based on traffic counts (Technique 3). However, the research team confirmed that the exact method used to generate these forecasts could not be determined: although the study reported ADTs from 1965, 1970, 1975, 1980, 1985, and 1986 for each link, the research team could not find a way to use these volumes to generate the 2010 forecasts reported in the study.

Study-specific assumptions made by the research team are given in Appendix B. For example, for one study titled the George P. Coleman Bridge Financial Alternatives Study (VDOT, 1989a), the base year appeared to be 1986, given that that was the last year volumes were available for the study (VDOT, 1989a). However, an examination of the study (VDOT, 1989a) showed that supporting information for the forecasts came from an earlier study (VDH&T, 1984d), which might lead one to suppose that the base year was earlier that that chosen by the research team.

Apply Techniques From the *Guidebook* to Virginia Studies

To verify that the 11 techniques listed in Table 1 (i.e., the selected techniques from the *Guidebook* and those identified by the research team) could be applied as written, the research team applied each technique to at least one study. The example calculations for each technique are given in Appendix A.

- *Forecasts of ADT, AWDT, or ESALs*. Technique 1 (adjusted regional model outputs) and Technique 2 (trend analysis of regional model outputs) were applied to a study based on a TDM (Study 20). Technique 3 (linear growth based on two traffic counts) and Technique 4 (regression based on multiple traffic counts) were applied to the Route 3 Corridor Study (Study 1). Technique 7 (ESAL estimation) was applied by modifying Equation 5.5 in the *Guidebook* to address a typographical error and was applied to the same corridor studies noted. Technique 9 (population-based forecasts) was applied to the Route 3 Corridor study (Study 1). Technique 11 (the traffic shift method for corridors) was applied to a new data set that consisted of two parallel roads that was suitable for that particular method.

- *Forecasts of seasonal ADT or peak hour volume*. Technique 5 (seasonal adjustment factors) available from the *base year* when the Route 3 study (Study 1) was done was applied to the forecast year volume for the study. These forecasts of seasonal ADT were compared to actual seasonal ADT in Studies 3 and 38. Technique 6 (peak hour link forecasting) was applied in a similar manner to Study 1: for select links report the K-factor for the base year, forecast the K-factor for the forecast year, and then report the difference between the actual peak hour volume and the forecast peak hour volume. Technique 10 (ITE-based factoring) was applied to a traffic impact analysis (Study 38).

- *Intersection forecasts.* No examples were found where the Fratar method had been applied. Accordingly, the research team identified an intersection where counts had been taken at least 2 years apart. Then, Technique 8 (Fratar method) was applied by developing a spreadsheet to the intersections listed as Study 37.

After applying each technique, the research team documented any additional information needed to apply the technique beyond what was provided in the *Guidebook.* This documentation became the basis for the first recommendation of this study.

Report Accuracy of Traffic Forecasts in the Virginia Studies and Compare With Accuracy Reported in the Literature

Error is the difference between the forecast volume and the observed volume, such that a positive error means that the forecast was higher than the observed value. For long-term forecasts, if the forecast year and the observed year were within 2 years of each other, no adjustment was made (e.g., for a forecast made in 2015, it would be ideal to have 2015 observed volumes; however, volumes as far back as 2013 were tolerated). If the forecast year exceeded the observed year by more than 2 years, however, then, based on a linear increase in traffic volume, the forecast was lowered to reflect an interim forecast that could be compared to observed data.

When multiple forecasts are aggregated, at least eight measures of accuracy are possible: mean error, mean absolute error, mean percent error, mean absolute percent error, median error, median absolute error, median percent error, and median absolute percent error. The first four measures are defined in Equations 2 through 5, with Equations 4 and 5 based on Wang (2014):

$$\text{Mean error } = \frac{1}{n}\sum_{i=1}^{n}(y_{\text{forecast}} - y_{\text{observed}}) \qquad \text{[Eq. 2]}$$

$$\text{Mean absolute error} = \frac{1}{n}\sum_{i=1}^{n}|y_{\text{forecast}} - y_{\text{observed}}| \qquad \text{[Eq. 3]}$$

$$\text{Mean percent errror} = \frac{100\%}{n}\sum_{i=1}^{n}\left(\frac{y_{\text{forecast}} - y_{\text{observed}}}{y_{\text{observed}}}\right) \qquad \text{[Eq. 4]}$$

$$\text{Mean absolute percent error} = \frac{100\%}{n}\sum_{i=1}^{n}\left|\frac{y_{\text{forecast}} - y_{\text{observed}}}{y_{\text{observed}}}\right| \qquad \text{[Eq. 5]}$$

where

$y_{forecast}$ = forecast volume
$y_{observed}$ = observed volume
n = total number of links or intersections in the study.

The last four measures, i.e., median error, median absolute error, median percent error, and median absolute percent error, are similar to Equations 2 through 5 except that “median” (the 50th percentile) replaces “mean.” A study with four links may be considered in which the errors (e.g., forecast minus observed volume) for each link are −300, −100, 100, and 700. Further, each link has an observed volume of 1,000. The mean error, mean absolute error, mean percent error, and mean absolute percent error would be 100, 300, 10%, and 30%, respectively. The median error, median absolute error, median percent error, and median absolute percent error would be 0, 200, 0%, and 20%, respectively.

A set of expected forecast errors based on these results was developed, and these expected forecast errors formed the basis of the second recommendation of this study. These expected errors from Virginia data were compared to those that were reported in the literature in order to gain a better understanding of the factors that appear to influence forecast accuracy.

Determine Impacts of Explanatory Factors on Forecast Accuracy

As noted by Venkatanarayana (2015), forecast accuracy is governed by two distinct components: (1) the validity of the technique, and (2) the extent to which the assumptions made in applying the technique hold true. Accordingly, the research team sought to examine how four factors affected accuracy: (1) forecast method, (2) number of economic recessions (hereinafter recessions) between the base year and the forecast year; (3) duration; and (4) forecast type, i.e., whether the quantity being forecast is a 24-hour volume or a peak hour volume. An analysis of variance (ANOVA), along with a simple hypothesis test, was used to determine the impact of these factors.

RESULTS AND DISCUSSION

Four sets of results are presented, each corresponding to one of the major objectives of this study:

1. the accuracy of forecasts
2. assumptions inherent in applying these techniques
3. data requirements for applying these techniques
4. factors that explain a portion of the differences in forecast accuracy.

Accuracy of Forecasts

Data Available

Table 2 lists studies and data sources obtained by the research team where a forecast value and the observed value could be compared. The forecast method reflects the method used in the study to generate the forecast. A small number of studies (10) were based on regional TDMs, although this would not have been evident from a review of the titles alone. (For example, although the Route 29 Corridor Study has the word "corridor" in its title, it is based on a regional TDM for the Charlottesville area.) A smaller subset of the studies is classified as traffic impact analyses, which denote land development studies conducted to determine how a change in land use will affect nearby traffic. For instance, Study 28 (Stonefield in Albemarle County) entailed forecasts for a mixed use town center being developed at the intersection of a primary and secondary facility. Most of the studies listed in Table 2 were based on some type of trend analysis from previous years' traffic data. This categorization also applies to the statewide forecasts shown in Studies 23, 24, and 25 based on conversations with the TRP (Paul Agnello, personal communication, March 27, 2015). For the few studies where the method could not be determined, the categorization of "UK," which stands for "unknown," is given in Table 2.

Table 2. Virginia Studies and Data Sources Supporting a Comparison of Forecast and Observed Volumes

Study No.	Title (Source)	Study Type[a]	Published Year[b]	Base Year	Forecast Year	What Was Forecast[c]	No. of Links[b]	Recessions [d]
1	Route 3 Corridor Study: Northern Neck and Middle Peninsula (VDOT, 1988a)	TRE	1988	1986	2010	ADT	19	3
2	George P. Coleman Bridge Financial Alternatives Study (VDOT, 1989a)	TRE	1989	1982	2005 2010 [g]	ADT [g] PHV	1	4 (2005) 4 (2010)
3	U.S. 15 James Madison Highway Passing Lane Study (UMA Engineering, Inc., 1997)	TRE	1997	1996	2016 (2014)[e]	ADT	1	2
4	Colonial Heights Thoroughfare Plan (VDH, 1970)	TDM	1970	1966	1985	ADT	21	4
5	York River Crossing Travel Demand Study (TransCore and Buchart-Horn, Inc., 2000)	TDM	2000	1990	(2014) [f]	ADT	39	3
6	Interstate 66 HOV Feasibility Study: Fairfax and Prince William Counties (Post et al., 1986)	TDM	1986	1985	2010	PHV	11	3
7	I-95/Clermont Avenue Interchange & Connector to Duke Street, Alexandria, Virginia (Louis Berger & Associates, Inc., 1990)	TDM	1990	1988	2010	AWT	28	3
8	Route 13 Corridor Study: Northampton County and Accomack County (VDOT, 1988b)	TRE	1988	1987	2010	ADT,	14	3
9	Routes 17 and 360 Corridor Study: Town of Tappahannock (VDOT, 1989b)	TRE	1989	1988	2010	ADT	5	3
10	Route 40 Needs Assessment Study: Campbell County, Charlotte County, Lunenburg County, and Nottoway County (VDOT, 1999a)	UK	1999	1996	(2014) [f]	ADT	17	2
11	Routes 20/240 Corridor Study: Albemarle County (VDOT, 1990a)	UK	1990	1987	2010	ADT	6	3
12	Route 608 Corridor Study: Augusta County, Fishersville, Stuarts Draft (VDOT, 1996)	TIA	1996	1994	2014	ADT	25	2
13	Botetourt County Route 220 Study (VDOT, 1999b)	TIA	1999	1994	2015 (2014)[e]	ADT	3	2
14	Capital Beltway Study: I-95/I-495 Northern Virginia: Short-Term and Mid-Term Recommendations Report (JHK & Associates et al., 1989)	TDM	1989	1988	2010	ADT	19	3
15	Route 221/460 Corridor Study: Roanoke and Botetourt Counties (VDOT, 2002)	TDM	2002	2000	(2015)[f]	ADT	3	2
16	Route 360 Corridor Study: Town of Warsaw (VDOT, 1993)	TRE	1993	1991	2010	ADT	7	3
17	Dulles Toll Road Extension Route 267: Draft Environmental Document (VDOT, undated b)	UK	Undated	1986	2010	ADT	8	3
18	Route 240 Corridor Study: Albemarle County (VDOT, 1990c)	UK	1990	1987	2010	ADT	2	3
19	Pulaski Area—Year 2000 Transportation Plan (VDH&T, 1981)	TDM	1981	1980	2000	ADT	56	3
20	Route 29 Corridor Study: City of Charlottesville and Albemarle County (U.S. DOT et al., 1990)	TDM	1990	1987	2010	ADT	17	3

Study No.	Title (Source)	Study Type[a]	Published Year[b]	Base Year	Forecast Year	What Was Forecast[c]	No. of Links[b]	Recessions [d]
21	Peninsula Area Transportation Study, Recommended Transportation Plan, Vol. II (Deleuw, Cather & Associates, 1967)	TDM	1967	1967	1985	AWT	174	4
22	Hampton Roads TDM Study (Michael Baker Jr., Inc., 2004)	TDM	2004	2000	2011	AWT	42	2
23	2010 Statewide Highway Plan: Culpeper District (VDOT, 1989c)	TRE	1989	1987	2010	ADT	240	3
24a	Statewide Highway Plan: Thomas Jefferson Planning District (VDH&T, 1984a)	TRE	1984	1981	2005	ADT	79	3
24b	Statewide Highway Plan: Richmond Regional Planning District (VDH&T, 1984b)	TRE	1984	1981	2005	ADT	46	3
24c	Statewide Highway Plan: 5th Planning District (VDH&T, 1984c)	TRE	1984	1981	2005	ADT	143	3
25	Statewide Highway Planning System (SHiPS) (a VDOT database)	TRE	Extracted in 2015	1994	2015 (2013)[e]	ADT	2,493	2
26	University of Virginia Research Park Study (Cox Company, 2008)	TRE	2008	2006	2015 (2014)[e]	PHV	9	1
27	Rivanna Village at Glenmore TIA Study (Cox Company, 2001)	TIA	2001	2001	2006 [g] 2011	PHV	4	1 (2006) 2 (2011)
28	Stonefield at Route 29 (Strohhacker, 2010)	TIA	2010	2010	2012	PHV	3	0
29	Town of Orange 2020 Transportation Plan Technical Report (Michael Baker, Jr., Inc., 2002)	TRE	2002	2000	2010	ADT	19	2
30	Route 360 Corridor Study: Hanover County, From Chickahominy River Bridge (Henrico County) to Pamukey River Bridge (King William County) (VDOT, 1990b)	UK	1990	N/A	2005	ADT	19	(2)
31	Route 10 in Chesterfield County Study (Johnson, 2001)	UK	2001	2001	2006 2014 [g]	ADT[g] PHV	4	1 (2006) 2 (2014)
33	Trip Generation and Distribution Study, Phase 1, West Creek, West Creek Parkway, Goochland County, Virginia (Frank Coleman & Associates, 1988)	TIA	1988	1997	2007	ADT	12	1
34	Route 1 Appomattox River Bridge and Approaches Location Study: Petersburg to Colonial Heights (Hayes, Seay, Mattern & Mattern, 1989)	TDM	1989	1987	2010	PHV	9	3
35	Route 1 Corridor Study: Fairfax and Prince William Counties (TransCore et al., 1997)	TDM	1997	1995	(2014)[f]	ADT	7	2
36	Richmond International Airport Corridor Feasibility Study (LPA Group and David Volkert & Associates, 1999)	TDM	1999	1998	2015 (2014)[e]	ADT	23	2
38	BJ's Wholesale Club Traffic Impact Assessment (Vanasse Hangen Brustlin, Inc., 2007)	TIA	2007	2007	2009 [g] 2015 (2014) [e]	PHV	10	1 (2009) 1 (2014)
39	Bell Creek Road Intersection Study (Johnson, 2002)	UK	2002	2000	2003 2014[g]	ADT[g], PHV	3	1 (2003) 2 (2014)

Study No.	Title (Source)	Study Type[a]	Published Year[b]	Base Year	Forecast Year	What Was Forecast[c]	No. of Links[b]	Recessions[d]
32[i]	Watkins Centre Traffic Impact Analysis (Volkert and Associates, Inc., 2007)	TIA	2007	2005	2024	PHV	NA	NA
37[i]	Old Keene Mill Road and Rolling Road Intersection Study: Fairfax County (Azimi, 2015a, b, c)	NA	Obtained in 2015	2005	2012	NA	12[h]	NA

VDH = Virginia Department of Highways; VDH&T = Virginia Department of Highways and Transportation; VDOT = Virginia Department of Transportation; U.S. DOT = U.S. Department of Transportation.
[a] TDM = travel demand model; TIA = traffic impact analysis; TRE = trend-based study; UK = type unknown (e.g., method is not stated).
[b] Parentheses indicate data as evaluated by the research team.
[c] ADT = average daily traffic; AWT = average weekday traffic; PHV = peak hour volume.
[d] The Federal Reserve Bank of Richmond (2016) has a graphic titled "Decomposition of Real GDP" that shows when recessions have transpired. This column indicates the number of recessions between the base year and the forecast year inclusive.
[e] As noted in Appendix B, because the 2015 volumes were not available, the volume for the year in parentheses was used to evaluate forecast accuracy.
[f] As noted in Appendix B, the original forecast year was either 2020 or 2018, so linear interpolation was used to determine the forecast for the year in parentheses.
[g] As more than one forecast was available for this study, this is the forecast that was used for Table 3.
[h] As these were intersections, this field denotes the number of turning movements.
[i] Studies omitted from the analysis in Table 3.

Three studies listed in Table 2 did not clearly fall into these categories. For Study 13 (Botetourt County Route 220), the background traffic was generated using a regional TDM; then additional trips were generated with what the study (VDOT, 1999b) referred to as "the Institute of Transportation Engineers' (ITE) Trip Generation Manual." Because of the ITE emphasis, the research team classified Study 13 as a traffic impact analysis (TIA). For Study 26 (University of Virginia Research Park), most of the proposed development was not built, and thus the focus of the evaluation was the growth in background traffic (which was a trend-based forecast as noted in Table 2). For Study 27 (Rivanna Village at Glenmore), a portion of the development was built (which entailed the use of ITE trip generation rates) yet a portion of the traffic was forecast using a trend-based analysis. Thus there is some debate as to whether the study's forecast method should be classified as a trend analysis or a TIA; the research team chose TIA as the method for this study.

The number of links (or in the case of Study 37, the number of intersections) also varies. An extreme example is the case of the George P. Coleman Bridge, where the study (VDOT, 1989a) had just 1 link—the bridge itself. By contrast, the York River Crossing Travel Demand Study (TransCore and Buchart-Horn, Inc., 2000) included 41 links, and the statewide SHiPS study (Study 25) entailed more than 2,000 links. (In some cases, the number of links in the study was different from the number of links for which an evaluation was conducted. For example, for Study 28, there were 8 links that were modeled; however, observed data were available for only 3 of the links.) Naturally, the geographical scope of these studies also varied. Whereas the Route 3 Corridor Study spanned multiple counties and almost 90 miles, the Botetourt Route 220 Corridor study focused on about one-tenth of that length.

The duration, i.e., the time elapsed between the base year and the forecast year, also varied. Clearly many of these studies supported a (roughly) 20-year long-range planning horizon; for instance, the I-95 Clermont Avenue Interchange study, published in 1990, provided forecasts for year 2010. However, some studies reflected a shorter time frame, especially some of the land development studies. Notably, Studies 28 and 38 (Stonefield at Route 29 and BJ's Wholesale Club) reflected periods of less than 5 years; in these cases, immediate land development was expected. In some cases, the year in which the forecast was "published" is not the year for which base data were available, as shown in Table 2. For instance, although the George P. Coleman Bridge Financial Alternatives Study was published in 1989, it made use of base year data from 1982.

Not shown in Table 2 but discussed in Appendix B is the fact that for some of these studies, forecasts were iterative. For example, for Study 28, although the forecast made in 2010 for the year 2012 was reported, earlier forecasts were made in 2001, 2002, 2005, and twice in 2009. Although some forecasts took the form of a bound report with a clear date of publication, other forecasts took the form of computer files or memoranda that could be obtained only internally (e.g., Study 31). In such cases, there were multiple "forecasts" that were then revised as new information became available. In other cases, multiple sources were needed to understand how a forecast was generated; for example, for Study 21, although forecast ADT were available from Volume II of the study (Deleuw, Cather & Associates, 1967), it was helpful to the research team to verify that a TDM had been used to forecast these ADT by reviewing Volume I of the study (Wilbur Smith and Associates, 1965).

Table 2 shows a total of 41 studies: these are numbered from 1 to 39, with there being Studies 24a, 24b, and 24c. Ultimately, 2 studies were not used for the evaluation of accuracy: Study 37 (because it required the research team to generate a portion of the forecast) and Study 32 (because of the relatively long length of time between the year for which observed volumes were available and the horizon year of the study). Accordingly, these 2 studies are shown at the bottom of Table 2.

Evaluation of Accuracy for Virginia Studies

As noted in the "Methods" section, a limitation of any retrospective evaluation is that it is not always possible to align a forecast value and the observed value. Two examples of this limitation were noted in the method: (1) the forecast may have presumed certain improvements (which were never built), and (2) the forecast may be for a portion of a road segment, whereas an observed volume may be for a much longer portion of that segment. As is evident from a review of Appendix B and Table 2, an additional example is the unanticipated economic or operational changes that may have transpired after the forecast was generated. For example, for the George P. Coleman Bridge (Study 2), the toll was not precisely what was expected (which could logically affect travel demand), and studies that were based on expected land use changes (such as travel demand modeling efforts) would not have foreseen the impacts of recessions that have been observed in Virginia. Thus there may be a variety of reasons that forecast and observed volumes differ.

Table 3 provides the eight measures of accuracy for each study. For example, for the Route 3 Corridor Study, for the 19 links, the mean error—that is, the mean difference between the forecast value and the observed value—was 3,079 vpd. Because the forecast for each of these 19 links was an overprediction, the mean error and the mean absolute error were identical. If the error for each of the 19 link is divided by the corresponding observed value, the average of the error percentages was 61%. Because 2 of the 19 links showed large errors (7,100 and 10,125 vpd), the median error was considerably smaller than the mean error for this study; for instance, the median percent error was only 41% compared to the mean error of 61%. The tendency for forecast volumes to be higher than the observed volumes was the case for most, but not all, of the studies. Of the 39 studies in Table 3, about three fourths had a positive mean error (30 studies) or median error (31 studies).

For Study 1 the forecast volume exceeded the observed volume for all 19 links, which is why the mean absolute error and the mean error were identical. This occurred, however, in only about one-third (13) of the 39 studies where error statistics were tabulated. For the remaining 26 studies, it was the case that in each study there was one or more links where the forecast volume was higher than the observed volume and one or more links where the forecast volume was lower than the observed volume. Within these 26 studies, some of these positive and negative errors tended to cancel, meaning that the mean error was lower than the mean absolute error. For example, for the Colonial Heights Thoroughfare Plan (Study 4) there were 21 links: 14 had positive errors (forecast value being greater than observed value) and 7 had negative errors (forecast value being smaller than observed value). The average of these errors (about 5,524 vpd) was less than the average of the absolute value of each error (7,690, as shown in Table 3).

Table 3 indicates that accuracy varied by study and in some cases by up to two orders of magnitude. For example, the most accurate study was Study 18 (the Route 240 Corridor Study) with the forecast volume and observed volume differing by only 35 vehicles—about 1% of the observed volume. By contrast, one of the least accurate studies was Study 13 (another corridor study but focused on Route 220), which showed an average error of almost 22,000 vpd, such that the error alone was greater than the observed volume (shown as 107%) in Table 3.

It should be noted that some of the studies in Table 3 included peak hour volumes rather than ADT or AWT, which will affect the magnitude of the error. However, the median and mean percent errors, as well as the median and mean absolute percent errors, provide one way to obtain an overall understanding of the forecast accuracy. For example, the last two rows of Table 3 indicate that the "mean of the means"—that is, the mean of the mean percent errors from each of the 39 studies—is 42%. Because positive and negative errors tend to cancel when absolute values are not used, and because a few studies with very large errors (or very small errors) can influence a mean, the research team suggests that the mean of the *median* absolute errors may be a useful measure to summarize forecast accuracy. That is, Table 3 shows that for the 39 studies, the median absolute percent error ranged from 1% (most accurate) to 134% (least accurate). The average value of the median absolute percent error of all studies was about 40%. That is, for a given study in which no information was given about the technique used, duration, or other explanatory variables, one would expect the median absolute error for all the links in the study to be about 40%, on average.

Table 3. Summary Error Statistics for the Virginia Studies

Study No.[a] (1)	Mean Error (2)	Mean Absolute Error (3)	Mean Percent Error (4)	Mean Absolute Percent Error (5)	Median Error (6)	Median Absolute Error (7)	Median Percent Error (8)	Median Absolute Percent Error (9)
1	3,079	3,079	61%	61%	2,430	2,430	41%	41%
2	7,178	7,178	24%	24%	7,178	7,178	24%	24%
3	4,375	4,375	73%	73%	4,375	4,375	73%	73%
4	5,524	7,690	32%	53%	5,830	6,170	31%	45%
5	4,992	6,108	102%	118%	1,431	2,128	56%	58%
6[b]	-73	934	-5%	22%	-325	854	-13%	20%
7	10,861	22,992	69%	72%	8,577	15,483	50%	50%
8	1,964	2,735	12%	16%	1,829	2,404	16%	16%
9	6,388	6,388	70%	70%	4,521	4,521	57%	57%
10	756	1,439	39%	53%	812	972	32%	39%
11	-1,110	1,227	-18%	20%	-430	570	-6%	8%
12	6,737	7,017	118%	126%	3,749	3,749	71%	71%
13	21,959	21,959	107%	107%	18,971	18,971	134%	134%
14	41,726	41,726	24%	24%	40,471	40,471	22%	22%
15	7,503	7,503	30%	30%	6,708	6,708	31%	31%
16	3,804	3,804	66%	66%	4,266	4,266	37%	37%
17	-7,225	9,775	-16%	23%	-5200	6,900	-14%	19%
18	-34	35	-1%	1%	-34	35	-1%	1%
19	2,118	2,492	61%	68%	2,488	2,570	49%	51%
20	3,508	4,055	52%	58%	2,585	2,585	15%	22%
21	-5,887	8,100	2%	56%	-1175	3,605	50%	38%
22	1,036	4,689	14%	47%	570	3,136	4%	35%
23	1,153	2,419	33%	48%	549	987	19%	31%
24a	-539	1,449	-3%	36%	-276	664	-13%	26%
24b	-972	2,425	12%	48%	-93	864	-6%	37%
24c	-216	1,590	58%	70%	210	439	25%	36%
25	4,258	4,368	112%	113%	1,794	1,854	72%	72%
26[b]	383	383	35%	35%	141	141	29%	29%
27[b]	-6	86	5%	10%	40	61	8%	10%
28[b]	1,016	1,016	40%	40%	509	509	35%	35%
29	1,358	1,697	22%	27%	1,064	1,330	16%	17%
30	2,304	3,157	58%	64%	810	1,000	59%	59%
31	4,450	4,450	40%	40%	4,665	4,665	34%	34%
33	-7,689	8,683	-20%	33%	-5,219	5,219	-19%	24%
34[b]	776	776	103%	103%	721	721	86%	86%
35	22,006	22,006	78%	78%	21,502	21,502	65%	65%
36	3,452	9,217	8%	43%	1,405	8,439	7%	36%
38[b]	142	251	13%	17%	131	234	10%	12%
39	11,847	11,847	114%	114%	11,740	11,740	40%	40%
Min.	-7,689	35	-20%	1%	-5,219	35	-19%	1%
Max.	41,726	41,726	118%	126%	40,471	40,471	134%	134%
Mean	4,177	6,439	42%	54%	3,829	5,140	31%	40%
Median	2,118	4,055	35%	48%	1,405	2,570	31%	36%

[a] The names of the studies are provided in Table 2.

[b] For Studies 6, 26, 27, 28, 34, and 38, error statistics reflect the peak hour volume rather than the 24-hour volume.

Accuracies Reported in Other Literature

In terms of comparing these results with those reported elsewhere, the literature is divided regarding how error should be defined. Some literature, consistent with the approach used in this study, defines error as the forecast value minus the observed value such that a positive result is an overprediction (CDM Smith et al., 2014; Tsai et al., 2013). Other literature does the opposite, defining error as the observed value minus the forecast value where a positive value is an underprediction (Flyvbjerg et al., 2005; Nicolaisen and Naess, 2015; Welde and Odeck, 2001).

When error is reported as a percentage such that the error is in the numerator, the denominator may be the observed value (Tsai et al., 2013; Xu et al., 2015) as done in this study, or the forecast value (Flyvbjerg et al., 2005; Nicolaisen and Naess, 2015; Welde and Odeck, 2001). An advantage of the former is that the percentage is expressed in terms of a real quantity (observed traffic); an advantage of the latter is that when the forecast is made, uncertainty can be expressed in terms of the forecast value since the observed value is unknown (J. S. Gillespie, personal communication, May 29, 2015).

If the observed volume and forecast volume are similar in terms of orders of magnitude, the question of how to present error on a percentage basis may not affect the reported errors substantially. The same cannot be said, however, with regard to whether one uses error or absolute error when aggregating individual links. For example, Flyvbjerg et al. (2005) examined 183 highway forecasts, reporting an average error of 9.5%. This average value included projects for which overestimated demand cancelled a project that underestimated demand. Calculations performed by the research team using the reported histogram of project percent errors available in Flyvbjerg et al. (2005) suggested that the average of the absolute project percentage errors would be approximately 32%. Thus when a study has more than one link, the median (or mean) percent error that is reported will be affected by whether or not absolute values were used.

The research team is not aware of many studies that report the accuracy of forecasts for a variety of study types in a given state. Examples of studies in which retrospective accuracy was examined include the aforementioned Flyvbjerg et al. (2005), Brett and Snelson (1999), Buck and Sillence (2014), and Parthasarathi and Levinson (2010).

- Brett and Snelson (1999) reported three examples of privately funded infrastructure in the United Kingdom: the Estuarial toll crossing where observed volumes were 40% higher than forecast volumes, the Humbler Bridge where observed volumes "were within a very small percentage" of forecast volumes, and a rapid transit system where there was a ridership "shortfall" that exceeded 50%. Errors of this magnitude are shown in Table 3 based on the 39 studies where error statistics were tabulated (e.g. Study 3 has an error of 73%). By contrast, the 32% for the average of the absolute project percentage errors noted by Flyvbjerg et al. (2005) was nominally lower than the 54% reported in Table 3. For both studies, however, one could argue that comparison with Virginia is not appropriate: Table 3 does not include transit forecasts (whereas Brett and Snelson did), and Table 3 does include forecasts for peak hour volumes, whereas Flyvbjerg et al. appeared to be focused on ADT (although the research team is not certain of this).

- Buck and Sillence (2014) evaluated 131 Wisconsin forecasts and reported that the mean and median absolute differences were 16% and 13%, respectively. Using data reported by Parthasarathi and Levinson (2010) for 108 Minnesota studies, where for each study, the mean percent error was reported, the research team calculated that the mean of these 108 mean errors was 8% (where positive and negative values cancel) but the mean of the absolute value of the average error from each of the 108 studies was about 30%. For both studies (Buck and Sillence, 2014; Parthasarathi and Levinson, 2010), these reported errors were lower than those shown in the last two rows of Table 3. However, there are some differences that hinder a direct comparison. For the Wisconsin study, none of the forecasts spanned a 20-year horizon, meaning they had shorter time periods, generally, than those noted in Table 3. For the Minnesota studies, the research team could not calculate the mean absolute percent error (e.g., Column 5 for each study). Because the Minnesota studies showed only the mean percent error (e.g., similar to Column 4 in Table 3), the research team could calculate only the absolute value of that quantity.

- CDM Smith et al. (2014) reported a survey in which planners were asked what level of accuracy should be expected as a function of the length of the planning horizon. The findings from that work were that for a 5-year horizon, errors of ±20% for an existing facility and ±27.5% for a new facility should be expected. For a 20-year horizon, the expected errors for an existing or new facility were ±42.5% and ±47.5%, respectively.

With regard to how Virginia forecasts compare with those reported elsewhere, on balance, the percent errors shown in Table 3 appear higher than those reported by Flyvbjerg et al. (2005), Buck and Sillence (2014), and Parthasarathi and Levinson (2010), although they are within the range of errors reported by Brett and Snelson (1999) and CDM Smith et al. (2014). However, for the reasons noted (e.g., forecast type, duration, and manner in which accuracy is calculated), one can find reasons to challenge a comparison between the studies reported in Table 3 and those reported elsewhere. For example, VDOT (2005a) noted that the peak hour volume could be computed in several ways, including as the 30th highest hourly volume (from a continuous count station), as the highest hourly volume over a 48-hour period (when temporary counts are performed), or as the peak hour volume from a neighboring link.

Two Elements of a Potential Best Practice for Forecasting

A review of the forecast errors noted in the literature and in Table 3 would suggest that forecasts are best presented as a range rather than a single number. This suggestion was noted by Welde and Odeck (2011), for instance, who suggested the use of a "confidence interval illustrating the inherent uncertainty in a project evaluation." Thus although minimizing future errors can be the motivation for retrospective study (Buck and Sillence, 2014), Nicolaisen and Driscoll (2014) demonstrated that explicit mention of the possibility of forecast error may be warranted, especially given the challenges in comparing forecast and observed volumes as noted herein. Thus one best practice would be to provide a range of expected error.

Hartgen (2013) suggested also what might be a second element of a best practice: understanding what types of forecast errors are needed based on the purpose of the study. For example, Hartgen (2013) suggested that a forecast error of 20% might be tolerable for designing a new facility but that a much smaller error may be essential for determining pavement design. A study by the LPA Group and David Volkert & Associates (1999) demonstrated this second element: the authors indicated that a certain alternative would remain "economically feasible" provided the forecast error did not exceed a certain error, which, when defined in the manner done by the research team for the current report, was 50% (for a connector from I-64) and 400% (for a connector from I-895). That is, the study (LPA Group and David Volkert & Associates, 1999) would suggest that even with the errors shown in Table 3, the forecast error would not alter the economic element cited in the study.

Assumptions Inherent in Applying Techniques From the *Guidebook*

Although Table 3 reports the forecast accuracy for previous studies, it does not indicate the assumptions that a planner must make when applying these techniques. Through application of the techniques in Appendix A to some of the data available from the studies, there appear to be five assumptions that result when these techniques are applied:

1. The technique may require input data that themselves must be forecast.

2. The technique may use data from multiple time periods.

3. The impact of forecast error on a decision is driven by the situation for which the forecast is needed.

4. Technique selection entails an implicit judgment about whether historical trends or expected future activity is a better predictor of future travel demand.

5. Additional data may not necessarily improve forecast accuracy.

Technique May Require Input Data That Must Be Forecast

One observation is that errors can compound when techniques that build on other techniques are applied. Technique 3 (trend line forecasting) and Technique 6 (computation of a peak hour volume given a K-factor) may be considered as examples. Since Technique 6 requires two forecasting elements—an ADT from Technique 3 and then a K-factor to obtain a peak hour volume—it is possible for errors to compound. This was observed in the evaluation of Study 3, where a forecast ADT of 10,360 exceeded the observed ADT of 5,985 by 73% (Technique 3) yet the peak hour forecast volume of 1,036 exceeded the observed hourly volume of 548 by 89% (Technique 6). A contributing factor to the greater error of Technique 6 was that the K-factor had decreased from a forecast value of 0.10 to an observed value of 0.092. Table 4 shows the error for the three studies that forecast both ADT and peak hour volume: in all three cases, the use of the extra data element—the K-factor—led to a larger median percent error than was the case with ADT only. (The difference was significant: $p = 0.04$.)

Table 4. Accuracy for Three Studies That Forecast Both ADT and Peak Hour Volume

Study No.[a]	Forecast Year	Average Daily Traffic		Peak Hour Volume	
		Median Error	Median Percent Error	Median Error	Median Percent Error
2	2010	7,178	24%	712	34%
31	2006	3125	19%	1,131	85%
31	2014	4665	34%	1,211	100%
39	2003	8,200	30%	771	57%
39	2014	11,740	40%	1,152	52%

[a] The names of the studies are provided in Table 2.

A second example is with Technique 8 (Fratar method), which is used to forecast turning movements at an intersection using two inputs: base year intersection turning movements, and forecast year link volumes. The Fratar method was applied twice to a set of 2005 base year data: once with observed link volumes for forecast year 2012, and once where forecast year link volumes had an average forecast error of 12.22%. The value of 12.22% was chosen based on Buck and Sillence (2014) who reported this average forecast error for links where a TDM had been used, which could be a typical application of the Fratar method. By turning movement, the mean absolute error is about 24 vehicles (13%) if the link volumes are forecast perfectly. With a mean absolute link volume error of 12.22%, the mean absolute error for turning movements is about 81 vehicles (or about 34%). That is, the forecast of the link volume is one input data element, and then the forecast of the turning movement is a second input data element.

As a third example, the traffic shift method for corridors (Martin and McGuckin, 1998) may be considered. This can be derived from the theory of utility maximization, which forecasts how an improvement to a given route will attract traffic to that route from alternative routes. An example is two roughly parallel routes in Virginia (I-64 and U.S. 60) where a lane was added to I-64, with construction completed in 2006. Based on the volumes in 2001 (prior to the improvement and a year for which volumes are available) and a forecast of how the improvement would affect speed on I-64, the change in volume for each route in 2007 (after the improvement has been made) can be forecast. Appendix A shows that if the total volume (from both routes) is known for the forecast year of 2007, the method is strikingly accurate, with an average absolute percent error of about 2%. However, because the total volume decreased—which might not have been expected in this urban area—the average absolute percent error was about 27%. To be clear, although the purpose of the traffic shift method for corridors is to forecast diversion based on an improvement, Appendix A shows that the accuracy of this method is affected by the accuracy of its inputs.

As a fourth example, Techniques 1 and 2, which adjust regional TDM outputs based on differences between the observed and forecast volume, may be considered. Table 5 shows the application of Techniques 1 and 2 to Study 20; the top row, labeled Technique 0, is the original forecast. Table 5 shows that in this particular case, the two adjustment techniques did not materially affect the error—in fact, they nominally lowered the accuracy of the forecast.

Table 5. Summary Error Statistics for Applying Techniques 1 and 2 to Regional Travel Demand Model Outputs From Study 20

Forecasting Technique[a]	Mean Error	Mean Absolute Error	Mean Percent Error	Mean Absolute Percent Error	Median Error	Median Absolute Error	Median Percent Error	Median Absolute Percent Error
0	3,508	4,055	52%	58%	2,585	2,585	15%	22%
1	5,074	5,139	54%	56%	3,900	3,900	26%	26%
2	5,538	5,615	57%	59%	3,783	3,783	34%	34%

Study 20 = Route 29 Corridor Study (U.S. Department of Transportation et al., 1990); Technique 0 = Forecast from the regional travel demand model; Technique 1 = Adjusted regional model outputs, Technique 2 = Trend analysis of regional model outputs.

Technique May Use Data From Multiple Time Periods

The Stonefield land development study (Study 28) may be considered an example of a study that uses data and produces a forecast from more than one time period. Traffic-related forecasts generated for Stonefield were made on at least seven occasions: 2001, 2002, 2005, 2009 (June and then December), 2010, and 2011 (see Table 6).

Among these seven forecasts, four differences were noted. First, the expected amount of development that would occur at the site changed dramatically: the amount of retail planned at the site varied such that the most recent forecast (2011) was 31% of the square footage planned in 2001. Second, the buildout year changed from 2006 (for all phases) to 2012 (for just Phase 1). Third, the traffic not generated by the site per se but the traffic to which the site traffic could be added was changed. This included both the background traffic (e.g., a 2% growth rate for traffic was presumed in the original 2001-2002 TIA, whereas a negative growth rate was observed in 2009) and the internal capture rate, which (including pass-by trips) varied from 21% (in 2001) to 30% (in 2005) with values of 24% in 2010 and 2011. Fourth, the focus of each study varied: for example, the 2010 study addressed whether an access management exception should be granted on Hydraulic Road, whereas the 2011 study examined whether a multi-way stop-controlled intersection should be installed internal to the site.

Table 6. Information Available for the Seven Stonefield Study (Study 28) Traffic Forecasts[a]

Data Element	2001	2002	2005	2009 (June)	2009 (Dec)	2010	2011
Apartments, condos, or townhouses	600	715	877	450	170	160	394
Hotel (rooms)	--	150	150	120	130	120	135
Cinema	--	15 screens	--	49,000 ft^2	64,713 ft^2	64,343 ft^2	2,923 seats
Retail (ft^2)	715,700	655,000	697,964	443,200	215,287	206,300	219,135
Office (ft^2)	200,000	240,000	207,538	162,000	--	--	--
Internal trips (P.M.)	652	892	882	868	762	530	528
External trips (P.M.)	2,661	2,469	1,812	2,105	1,050	1,653	1,706
Internal trips (day)	--	7,549	--	8,667	--	3,939	5,313
External trips (day)	--	27,658	--	20,592	--	12,478	17,233
Hydraulic Road ADT[b]	19,385	19,731	19,136	17,173	17,173	17,254	16,995
Route 29 ADT[b]	61,378	61,092	56,980	55,890	55,890	56,510	55,312
Phase	This describes the entire project			This describes Phase 1 only			

[a] Data values were computed or derived from Ramey Kemp & Associates, Inc. (2002a, b); Bowman Consulting (2011), and unpublished sources within VDOT project files.
[b] These are observed values. Everything else in the table is a forecast.

Collectively, the seven studies suggested that in some cases a land development study will not have a single forecast but rather will have multiple forecasts that change as economic and traffic conditions evolve. The information gleaned from the seven studies describing Stonefield is described in Table 6.

Impact of Forecast Error on Decision Is Driven by Situation for Which Forecast Is Needed

The ADT for one section of the two-lane aforementioned Route 3 (Study 1) was forecast to be 9,800 in 2010. With an observed ADT of 6,100, the error was 3,700 (61% relative to the observed value). The question arises as to what error would cause decision makers to change their course of action.

The study (Study 1) identified improvements to achieve LOS C: having channelization at two intersections, widening the substandard pavement to 24 feet, improving the shoulder, and widening the segment from two to four lanes—a major capacity recommendation. LOS was the determinant of action; therefore, how the forecast error affected LOS can be examined. The report did not provide LOS computational details; however, when the forecast was generated in 1988, the method in the 1985 *Highway Capacity Manual* (described by Garber and Hoel, 1988) was standard practice.

Figure 1 illustrates how the forecast error influences decisions. Assuming no change to the roadway geometry, the research team calculated that 726 vph was the maximum volume that could support LOS D. The observed peak hour volume in 2010 was 537, which thus yielded LOS D. The forecast ADT was 9,800, yielding LOS E. Therefore, if the forecasters had assumed that the K-factor—the peak hour volume divided by the ADT—would remain constant for the period 1986-2010, the forecast hourly volume would have been 998 (86% error). If the forecasters had instead anticipated some peak spreading where the K-factor dropped to its observed value, the forecast hourly volume would have been 862 (61% error). Regardless of whether peak spreading was assumed, the forecast error results in an LOS E, rather than the correct value of LOS D, being computed. Yet because both the forecast and observed volumes were below LOS C, the error did not alter the judgment that the segment was deficient.

However, for a low-cost alternative where the pavement is widened to 24 feet, 6-foot shoulders are added, and no lanes are added, an hourly volume of 689 vehicles accommodates LOS C. The observed hourly volume (537) meets this LOS, but the forecast—with or without peak spreading—does not. Hence, the forecast error means that decision makers would have rejected (incorrectly) this low-cost alternative as they would have thought that widening to four lanes was essential to achieve LOS C. Figure 1 suggests that two distinct factors affect the impact of error on decision making: (1) the magnitude of the error, and (2) the location of the error relative to the performance criterion. In Figure 1, if the magnitude of the error had remained the same but its location had been shifted rightward by 152 or more vehicles, the decision maker would have assumed widening was necessary—regardless of whether the forecast value or the observed value was used in the decision.

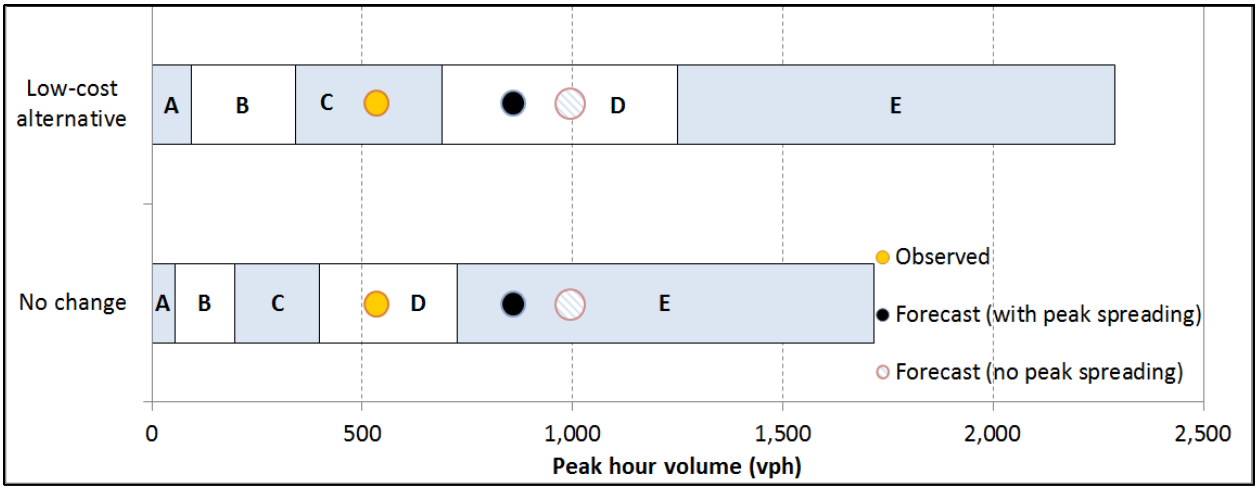

Figure 1. Level of Service (LOS) Standards (A through E) for Section of Route 3. Criteria for LOS were calculated by the research team based on the method of Garber and Hoel (1988) and data available in VDOT (1988a).

Technique Selection Entails Implicit Judgment About Whether Historical Trends or Expected Future Activity Is Better Predictor of Future Travel Demand

Application of the 11 techniques provided in Appendix A suggests that most can be split into two categories based on the data elements required.

1. *Some of the techniques are based on future expectations of land and demographic activity (i.e., are activity-based).* Techniques 1 and 2 (which adjust outputs from the regional TDM), Technique 9 (which uses an estimate of future population growth), and Technique 10 (ITE-based factoring) are largely based on one's expectation of how land development or population will change. Thus if one thinks that a change in land development—whether through population growth or estimates of what will be built—will drive travel demand, one of these techniques is appropriate.

2. *Some of the techniques are based on historical trends of travel demand (i.e., are trend-based).* Techniques 3, 4, 5, and 8, although they encompass different methods, essentially use existing patterns of travel to forecast future travel patterns. Techniques 3 and 4 extrapolate observed traffic counts for an annual average 24-hour day; Technique 5 uses previous seasonal trends to convert a forecast average to a count one would expect on a specific day of the week for a given month; and Technique 8 estimates intersection turning movements based on historical movements. Thus if one thinks that the past is a good predictor of the future, these techniques can be appropriate.

Two techniques do not fall neatly into the two categories because they can build on forecasts provided by the techniques noted. Technique 7 estimates ESALs based on forecast vehicle types for a given section of roadway. Technique 11 determines how a given travel time improvement for one facility will affect the quantity of traffic attracted to it from other parallel facilities. As shown in Appendix A, both techniques require an input forecast volume: for Technique 7, this forecast volume must be decomposable into heavy trucks, medium trucks, and autos; for Technique 11, this forecast volume represents the total volume on two or more parallel routes.

Additional Data May Not Necessarily Improve Forecast Accuracy

Table 5 showed that the inclusion of additional information—the difference between the base year modeled and observed volume, as illustrated by Technique 1—did not materially improve forecast accuracy relative to not applying the technique at all (and simply using the TDM forecast alone). As another comparison, Technique 3 (which uses only 2 years of traffic volumes) and Technique 4 (which uses multiple years of traffic volumes) were applied to the four corridor studies listed in Table 7.

The last row of Table 7 indicates the *p*-value for the particular error statistic based on the two techniques. For example, a paired *t*-test between Technique 3 and Technique 4 showed that the difference in the mean error for these two tests had a *p*-value of 0.17, meaning there was not a statistically significant difference between Technique 3 and Technique 4 in terms of how they affect the mean error.

There is a great deal of variation in Table 7: the mean absolute percent error for the four studies, for example, ranges from a low of 11% (based on Technique 4 for Study 8) to a high of 65% (the same technique but for Study 10). However, there is not a statistically significant difference between the accuracy of these two techniques based on any of the eight error measures shown in Table 7. That is, all of the *p*-values shown in Table 7 exceed 0.05.

Table 7. Summary Error Statistics for Techniques 3 and 4

Study No.[a]	Technique No.	Mean Error	Mean Absolute Error	Mean Percent Error	Mean Absolute Percent Error	Median Error	Median Percent Error	Median Absolute Error	Median Absolute Percent Error
1	3	1,634	1,922	37%	41%	846	17%	1,080	18%
	4	1,437	1,792	34%	40%	1,102	20%	1,336	22%
8	3	3,486	3,357	21%	21%	2,662	18%	2,551	15%
	4	43	1,837	0%	11%	-452	-3%	1,596	8%
9	3	4,412	4,412	54%	54%	2,615	33%	2,615	33%
	4	1,632	4,294	29%	45%	3,457	43%	4,205	43%
10	3	-871	1,702	-17%	58%	-694	-37%	1,650	59%
	4	-825	2,066	-6%	65%	-439	-14%	1,518	51%
p-value		0.17	0.45	0.34	0.45	0.66	0.71	0.74	0.97

Technique 3 = linear growth based on two traffic counts; Technique 4 = regression based on multiple traffic counts.
[a] The names of the studies are provided in Table 2.

Data Requirements for Applying Techniques

It is somewhat difficult to compare directly the number of data elements required for each technique because not all data elements require the same degree of effort. For example, it can be argued that Techniques 1 and 4 each require, at a bare minimum, just three data elements. Technique 4 requires a set of historical traffic counts in order to use a linear trend line to forecast future traffic counts, and at a minimum, a trend line could be established with three observations.

Technique 1 requires an observed volume from a base year, a forecast volume for the base year from a regional TDM, and a forecast volume for the forecast year also from a regional TDM. However, executing a regional TDM (associated with Technique 1) requires considerably more effort than obtaining traffic volumes from historical data sources. Accordingly, Table 8 compares the data required for each technique in matrix form, with the recognition that some data elements are easier to obtain than others.

Table 8 shows that four of the techniques (Technique 5, seasonal adjustment factors; Technique 6, peak hour link forecasting; Technique 7, ESAL estimation; and Technique 8, Fratar method) themselves require a forecast year volume. That is, in order to apply Techniques 5 through 8, one must first generate an ADT forecast using Technique 1, 2, 3, 4, 9, or 11; further, if one choose either Technique 1 or 2, one must also have a TDM. Technique 11, the traffic shift method for corridors, is a special case: it requires some estimate of total ADT on two parallel routes (hence it uses Technique 1, 2, 3, 4, or 9)—and then it can give the forecast of ADT for each such parallel route (which can then be used as an input for Techniques 5 through 8).

Table 8. Data Elements Required for the 11 Techniques Given in Table 1

Data Element	Technique										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Base year ADT forecast from regional demand model	X	X									
Future year ADT forecast from regional demand model	X	X									
Base year ADT	X		X	X				X	X	X	
Observed ADT from any 2 past years			X								
Observed ADT from any 3 or more past years				X							
Annual axle factor					X						
Seasonal adjustment factor					X						
Hourly volumes from a comparable route or forecast year volume/capacity ratio						X					
Number of lanes for the facility							X				
Percent cars							X				
Percent single unit trucks							X				
Percent tractor trailer trucks							X				
Base year intersection turning movements								X			
Base year population									X		
Forecast year population									X		
Forecast year land use types										X	
Free flow speed, capacity for base year parallel routes											X
Free flow speed, capacity for forecast year parallel routes											X
K-factor to convert ADT to peak hour volume						X					X
A forecast year ADT from Techniques 1, 2, 3, 4, or 9					X	X	X	X			X

Technique 1 = adjusted regional model outputs; Technique 2 = trend analysis of regional model outputs; Technique 3 = linear growth based on two traffic counts; Technique 4 = regression based on multiple traffic counts; Technique 5 = seasonal adjustment factors; Technique 6 = peak hour link forecasting; Technique 7 = ESAL estimation; Technique 8 = Fratar method; Technique 9 = population-based forecasts; Technique 10 = ITE-based factoring; Technique 11 = traffic shift method for corridors.

Table 8 also shows that except for a base year estimate of ADT, several of the techniques do not have overlapping data elements. For example, the free flow speed and capacity of each link is needed for only Technique 11 (where one compares how forecast year speeds will attract vehicles from a parallel route). A set of historical traffic volumes is needed for Techniques 3 and 4 in order to develop a trend line but not for ITE-based factoring, which requires land use codes for use with *Trip Generation* (ITE, 2008). ESAL estimation requires some way of determining the portion of ADT that is heavy trucks, medium trucks, and passenger automobiles—but such vehicle classifications are not needed for the other techniques.

Although effort must be expended to acquire current base year data, most of the data elements in Table 8 have a similar level of availability, with two caveats. First, Techniques 1 and 2 are applicable only in locations with a TDM—generally Virginia's MPO areas. Although these areas account for a majority of Virginia's population, they do not account for a majority of Virginia's jurisdictions. (That is, when the research team examined a document titled *Transportation Enhancement Program: Listing of MPO Areas* [VDOT, 2007], they tabulated that a majority of Virginia's 134 independent cities and counties (73) are not located within an MPO area.) Second, because not all roads in Virginia are state-maintained, the availability of volume data, especially historic volume data, is not uniform. Some locations have detailed count data available (VDOT, undated a), whereas other locations have periodic counts but not a routine approach for converting these periodic counts to an annual average (Smidler, 2015).

Accordingly, a review of Table 8 raises three key questions.

1. Are there material differences in the accuracy of these techniques, especially for techniques that make use of future demographic data (e.g., Techniques 1, 2, 9, and 10), relative to techniques that extrapolate previous traffic volumes (e.g., Techniques 3 and 4)?

2. If there are differences in technique accuracy, how does the error from an easier technique (e.g., trend line analysis such as Techniques 3 or 4) compare with the error from a more difficult technique (e.g. a TDM in Technique 1 or 2 or ITE-based factoring in Technique 10)?

3. Given that some of the techniques can produce a more detailed output than simply an ADT or AWT, (i.e., a peak hour volume, a turning movement, seasonal volume, or the number of ESALs), is there a difference in forecast accuracy between a more general output and a more specialized output?

Factors That Explain a Portion of the Differences in Forecast Accuracy

A limited number of specific factors that might explain the differences in forecast accuracy were identified through examination of Tables 2 and 3 and discussions of results with VDOT staff, including members of the TRP (Paul Agnello, Bill Guiher, Amy O'Leary, Ram Venkatanarayana, and Allan Yue, personal communication, February 17, 2016). In choosing the factors, three principles were followed. First, avoid having too many factors, given that one could erroneously identify spurious conclusions. Rather, pick a few factors that appear to be the most critical for the analysis. For example, although the research team was interested in the accuracy of all 11 techniques, given that there were only 39 studies in Table 3, it made more sense to focus on splitting the studies into two groups: those based on an extrapolation of past trends, and those based on demographic forecasts. (Although it was not possible to ensure that each independent variable had the identical number of observations for each level, it was possible to ensure that each cell had at least five observations.) Second, differentiate among the forecasts for ADT and the forecasts for more detailed variables that build on ADT, such as peak hour volume. Third, identify factors that are beyond the forecaster's control, such as changes in the economy or short-term versus long-term forecasts.

Factors Considered in Model Development

Based on these three principles, four explanatory factors were initially considered, with each factor identified at two levels based on the information in Table 2.

1. *Forecast method*. Does the study reflect some estimate of future activity such as a TDM or a TIA (i.e., activity-based) (19 studies) or is the study based on a historical trend analysis (i.e., trend-based) (20 studies)? This factor was named "Forecast Method" in the model.

2. *Recessions.* Is the number of recessions that occurred between the base year and the forecast year inclusive (based on information from the Federal Reserve Bank of Richmond, 2016) relatively small at 0 or 1 (5 studies), medium at 2 (13 studies), or larger at 3 or 4 (21 studies)? This factor was named "Recession" in the model.

3. *Duration.* Is the study truly a long-term forecast, where the forecast year minus the base year is 20 years or more (20 studies), or is the study a short-to-medium term forecast, where this difference is 19 years or less (19 studies)? This factor was named "Duration" in the model. This factor was named "Duration" in the model.

4. *Forecast type*. Is the study forecasting a 24-hour volume, such as an ADT or AWT (33 studies), or is it forecasting a peak hour volume (6 studies)? This factor was ultimately excluded from the model.

It was tempting to include the fourth factor (forecast type) as an independent variable. However, there were only six studies where forecast type was a peak hour volume; further, given that the results of Table 4 had shown that forecasts for a peak hour had greater errors than forecasts for a 24-hour volume, this factor was eliminated.

In classifying studies based on the remaining three factors, four assumptions were made. For the first factor—forecast method—if the forecast type was "unknown" in Table 2, then it was classified along with studies based on a historical trend analysis. For the third factor—duration—there were studies where Table 2 shows an observed year that was earlier than the forecast year, and for such studies, duration was computed as observed year minus base year. For Study 30 only, as the base year was not known, the base year was assumed to be the published year. Finally, the word "inclusive" which is used to describe the recessions factor means that if a recession began or terminated in the base year or forecast year, that recession was considered to have occurred between the base year and the forecast year. For example, three recessions (1991, 2002, and 2009) were recorded between the base year (1987) and the forecast year (2010) for the Route 29 Corridor Study (Study 20) as shown in Table 2.

Then, an ANOVA was conducted where the dependent variable was the median absolute percent error from each study (see Table 9). The reason for focusing on the median absolute percent error was threefold. First, by use of the median (rather than the mean), the dependent variable for a study would not be dramatically affected by a few links with very large (or very small) error values. Second, the reason for focusing on absolute error was such that positive and negative errors for individual links did not cancel. Third, the reason for focusing on a percent error (rather than a nominal error) was to enable a comparison of studies that forecast links with very different volumes (e.g., a forecast for an interstate corridor will tend to have a larger nominal error than a forecast for a secondary road to the extent that the former has larger volumes than the latter). (The necessity of controlling for different volumes was demonstrated when an ANOVA based on the dependent variable as the mean absolute error, rather than a percentage, was conducted: residuals were not normally distributed, and the best model explained at most 15% of the variation in forecast accuracy.)

Table 9. Results of Analysis of Variance of Median Absolute Percent Error

Model No.[a]	**Key Variables**[b]	***p* value**[c]	**Variance Explained**[c]	**Interpretation of Model Effects**
1	Forecast method Recession	0.48 (0.11) 0.03 (0.04)	18.2% (17.2%)	A trend-based forecast is more accurate than an activity-based forecast when the number of recessions between the base and forecast years is 2 or more.
2	Forecast method * Duration	0.01 (0.02)	15% (15.4%)	A trend-based forecast is more accurate than an activity-based forecast for long-term durations but not for short-term durations. Further, long-term trend-based studies are more accurate than short-term trend-based studies.
3	Forecast method * Duration Recession	0.04 (0.07) 0.02 (0.05)	29.1% (26.8%)	For both activity-based forecasts and trend-based forecasts, accuracy increases when duration decreases. For both cases, accuracy is lowest under the case of exactly 2 recessions. For long-term durations, trend-based analysis is more accurate than activity-based analysis, but for short-term durations, activity-based analysis is slightly more accurate than trend-based analysis.

[a] Models 1 and 2 were run as full factorials, but the interaction effect in Model 1 (Forecast method * Recession) and the main effects in Model 2 (Forecast method, Duration) are not significant. All terms for Model 3 are shown except the intercept, which was significant in all three models.
[b] Possible values for each variable are as follows: Forecast method (activity or trend); Duration (≤19 years or ≥20 years); Recession (number of recessions between base and forecast year (0-1, 2, or 3-4). Forecast type was ultimately excluded from the model.
[c] The value in parentheses is the result when the six studies that forecast a peak hour volume, rather than a 24-hour volume, are excluded.

Although it is possible to develop a full factorial model (based on recession, duration, and forecast method) that can explain 41% of the variance in the accuracy rates, such a model appears inappropriate because two of the independent variables (duration and recession) are highly correlated (0.85). Having two highly correlated variables interact with each other could lead to the false belief that spurious impacts were significant. Accordingly, the researcher team first considered each (but not both) of these variables along with forecast type in a full factorial model to explain the variation in the data set. These results are shown as Models 1 and 2 in Table 9, where recession (when treated as a main effect) and duration (when treated as an interaction effect that is combined with forecast method) each have a significant impact on error (p values are 0.03 and 0.01, respectively). Significance levels were similar whether all 39 studies or just the 33 studies that forecast a 24-hour volume were used.

The fact that these two correlated variables (duration and recession) have different forms in the full factorial ANOVA is troubling. Models 1 and 2 generate two additional concerns. First, the interpretation of the effects of these factors is at least counterintuitive; notably, for Model 2, when a trend-based analysis is performed, studies with a duration of 19 years or less between the base and forecast years appear to be less accurate than studies with a duration of 20 years or more. In addition, the hypothesis of normality (desirable for ANOVA) can be rejected based on the Kolmogorov-Smirnov test ($p = 0.02$ and 0.03, respectively), which would suggest the need for some type of transformation or another model formulation.

Accordingly, a third model was considered—where it appeared appropriate to the research team to treat the number of recessions as a block. A block can be described generally as "a set of relatively homogeneous experimental conditions" (Montgomery, 2001); it in practice, a block may be a factor that should affect the results but that is not controlled by the forecaster. Although the forecaster can choose the forecast method and the duration, the number of recessions is in fact a nuisance variable: it is an effect that must be controlled for when results are analyzed, but it is not a decision that the modeler can make at the outset of the study. Model 3 explicitly accounts for the impacts of recessions but allows for one to consider the impact of duration (addressing a concern with Models 1 and 2). Model 3 also shows that the residuals are normally distributed ($p = 0.75$), thereby addressing the research team's second concern with Model 2.

The implications of Model 3 are quite telling in several aspects. First, the number of recessions has a nonlinear impact—that is, errors were highest when the number of recessions was 2, rather than at a smaller number of recessions (0 or 1) or a larger number of recessions (3 or 4). Second, as one might expect, a shorter duration increases accuracy—but this is evident only when controlling for the confounding effect of recessions. That is, had recessions not been controlled for, one would have thought (based on Model 2) that in some cases having a longer horizon increases accuracy. Third, activity-based approaches are slightly more accurate than trend-based approaches, but only for shorter term studies; for longer term studies, the results of Model 3 suggest that trend-based methods are more accurate. This third result is surprising: one would have expected the activity-based approaches, which incorporate more detail (e.g., impacts of land development) to be more accurate than the extrapolation of past trends. Although the research team cannot prove this explanation, one possible reason is the following: in the short term, behavioral assumptions (e.g., attitudes toward driving or using public transportation) are more likely to remain constant, such that additional model detail (which comes from activity-based approaches) increases accuracy. However, in the longer term, it is possible that the change in behavioral assumptions becomes more likely such that the additional detail is not helpful.

Table 10 shows the estimated marginal means of the ANOVA for Model 3. Duration and forecast method have significant and mostly expected impacts on forecast accuracy but only if confounding effects are controlled for in at least three ways. First, one must consider the interaction effect between forecast method and duration: in the short term, activity-based studies are slightly more accurate than trend-based studies, but in the long term, the accuracy of these activity-based studies degrades substantially. A less dramatic decrease in accuracy is noted for trend-based studies as one changes from short term to long term. Second, as is evident from Table 9, one must control for changes in economic condition, which in this study is the number of recessions between the base year and the forecast year. Third, given that the studies have different facilities (e.g., eight lane interstate highways versus two-lane local roads) it is appropriate to control for differences in volumes by using the median absolute percent error instead of the median absolute error as the dependent variable.

Table 10. Estimated Marginal Means of Median Percent Error for Model 3

Forecast Method	**Duration (Time Between Base Year and Forecast Year)**	**No. of Recessions Between Base Year and Forecast Year Inclusive**		
		0 or 1	**2**	**3 or 4**
Activity [a]	Short term (≤19 years)	22%	49%	23%
	Long term (≥20 years)	50%	78%	51%
Trend [b]	Short term (≤19 years)	23%	50%	24%
	Long term (≥20 years)	26%	53%	27%

[a] Forecast uses expected future activity (population, employment, or land use); examples are travel demand models and traffic impact analyses.
[b] Forecast uses an extrapolation of previous volumes (or method was not given).

Factors Not Considered in Model Development

It is acknowledged that factors other than the four noted may have affected forecast accuracy. Although the research team was not able to model these factors explicitly through the ANOVA, at least three additional factors may have an impact on forecast error: (1) quality of observed traffic volumes, (2) facility volume and functional classification, and (3) implementation of fiscal constraint in TDMs.

Quality of Observed Traffic Volumes

In this study, observed traffic volumes were treated as ground truth against which the accuracy of forecasts was judged. However, these observed volumes themselves may have some variability from this ground truth for at least three reasons. First, most volumes in Virginia are temporal counts that are modified based on seasonal adjustment factors to obtain a yearly average. For example, in the Culpeper District, as of June 14, 2016, there were 14 continuous count stations—that is, links where traffic counts are collected 24 hours per day, 365 days per year—but there were 6,860 links in total. For the remaining 6,844 links, there is not a true annual average volume because there is no continuous count station. Rather, counts are taken for just a portion of the year (often a 48-hour period) and then factored to obtain an estimate of the annual average. VDOT’s databases provide an indication of this quality of traffic for counts taken after 1990 (e.g., average of continuous count data, average of selected continuous count data, some type of factoring, or a historical growth estimate), although this indication is not available for counts taken prior to 1990 (which was the case with Study 4, for example) or for which observed data came from incorporated cities that maintained their own count programs (which was the case with Study 38). Second, there is not a perfect alignment between forecast and observed count locations; for example, for Study 28, there was only one observed volume on Hydraulic Road between Route 29 and Commonwealth Drive, yet there were three separate forecast volumes (Route 29 to Swanson Drive, Swanson Drive to Cedar Hill, and then Cedar Hill to Commonwealth Drive). Third, as discussed in Appendix B, for land development studies it is often the case that what is forecast is a turning movement—which in turn must be converted to a link volume. As shown in Appendix B, this conversion process introduces ambiguity, i.e., more than one value for a link volume can be determined by two adjacent intersections. For example, for Study 26, the mean absolute percent error could change by about 7 percentage points (from 35% to 28%) depending on how turning volumes are converted to link volumes.

Facility Volume and Functional Classification

One question posed by the TRP is whether the percent forecast errors tend to be smaller for facilities that have larger demand, where the larger demand may be reflected as either a larger forecast volume (e.g., 50,000 rather than 5,000 vpd) or a higher functional classification (e.g., an interstate facility rather than a local facility).

The short answer is that link percent errors are generally smaller for facilities where a larger volume is forecast; however, this trend is difficult to detect unless one looks at different links in the same study. For example, for the studies that forecast a 24-hour volume (excluding Study 25), there is a total of 1,101 links. A correlation analysis between the forecast volume and the absolute percent error by link without accounting for differences in the studies showed a very weak negative correlation of -0.08. Given that a negative correlation can range from 0.0 (no relationship between percent error and volume) and -1.0 (percent error decreases strongly as volume increases), this initial result would suggest that the amount of demand has little impact on error.

However, stronger relationships between demand and percent accuracy became apparent when the studies were examined individually. Two types of studies that have a large number of links can be considered: TDMs, and trend-based regional or statewide studies. For example, for three of the regional TDMs (Studies 20, 21, and 22), the correlation between forecast volume and percent error when all 233 links from the three studies were analyzed together was a positive 0.17—a surprising and unexpected result. However, when each study's set of links was analyzed separately, the three studies yielded negative correlations (-0.20, -0.23, and -0.25) that showed to some extent that smaller percent errors are associated with larger forecast volumes. For example, for Study 21, the median percent error was 48% for links where the forecast volume under 10,000 vpd; for links with higher forecast volumes, the median percent error was 30%.

As another example, the 2,493 links that comprised Study 25 were analyzed. The forecasts for most of these links (1,665) were under 10,000 vpd, for which the median percent error was 74%. However, for the small number of links with a very large forecast (70,000 vpd or higher), the median percent error was 11%. Further, for that study, the median percent error for freeway/expressway segments (10%) was considerably lower than for the three other functional classifications included in the data set: urban arterial (71%), rural multi-lane (62%), and rural two-lane (75%). A similar pattern was noted for Study 22 with respect to functional classification: the mean percent error was lower for interstates (35%), moderate for arterials (38%), and higher for collectors (70%).

Implementation of Fiscal Constraint in TDMs

More than a decade before this study was undertaken, the Federal Highway Administration issued guidance to Virginia stating that the transportation improvement program should include only those projects that could realistically be built with the funds available (DeBruhl, 2002). It is possible that in urban areas that use a TDM, one would expect to see forecasts become more accurate after December 2002, given that the models would have a more realistic assessment of which projects would be built. However, of the studies listed in Table 2, only eight were published in 2003 or later, and of those, only one was based on a TDM. Accordingly, this particular factor was not included as an independent variable in the ANOVA.

CONCLUSIONS

- *On average, for Virginia forecasts from past studies, the median absolute percent error was 40%.* That is, for each of the 39 studies obtained by the research team listed in Table 3, one could (for each link in the study) divide the absolute error (the magnitude of the difference between the forecast volume and the observed volume) by the observed volume. Then, for each study, one could select the median absolute percent error from these ratios. The average of these median absolute percent errors would be 40%, as shown in Table 3.

- *Application of any forecast technique entails making assumptions or judgments regarding how to predict future behavior, the availability of data, and the impact of forecast error.*

  — *Methods to predict future behavior can be split into two categories: basing forecasts on future activity or basing forecasts on previous behaviors.* Four of the techniques (Techniques 1 and 2, which adjust outputs from the regional TDM; Technique 9, which uses an estimate of future population growth; and Technique 10, ITE-based factoring, are based on how one expects future land development will change. By contrast, Techniques 3 and 4 (extrapolation of observed traffic counts), Technique 5 (seasonal trends), and Technique 8 (Fratar method) are based on an extension of previous behavior to the future.

  — *The impact of a forecast error depends on the situation for which the forecast is needed.* For example, as shown in Figure 1, although the error was seemingly large at 61%, or about 370 vehicles during the peak hour, the error mattered only to the extent that it caused a shift from the criterion for action—which was whether a roadway needed an improvement to achieve an LOS of C or higher. That is, Figure 1 demonstrates that it is not necessarily the case that a large error (if corrected) would cause a change in actions taken by a decision maker.

— *The comparison of forecast and observed volumes is not necessarily clean.* As noted in Appendix B, complications such as expected improvements in a study not being made, observed volumes not being available at the same level of detail as forecast volumes, turning movements not being collected routinely, design hourly volumes (DHVs) being assumed to be peak hour volumes, substitution of ADT for AWT, and seasonal variation in traffic volumes can hinder a direct comparison between observed and forecast volumes. Accordingly, although the difference between a forecast volume and an observed volume is attributed to a technique or its application, for some links, a portion of the difference may also be attributed to experimental error.

- *In terms of data requirements for the 11 techniques, larger forecast errors are observed for traffic forecasting techniques that require data that must be forecast.* On a percentage basis, for the three studies that provided a forecast of both ADT and peak hour volume, the percent error for the latter was higher than for the former. As noted in Appendix B, for Study 31, two forecasts were generated: ADT and peak hour volume. For the 13-year horizon, the mean percent error was 40% for ADT but 96% for peak hour volume. A contributing factor was that a forecast for peak hour volume requires an additional piece of information not needed for ADT: the K-factor for the forecast year.

- *Four factors affect this median absolute percent error in a statistically significant manner (i.e., the p-value is 0.05 or less): (1) whether the forecast is for a peak hour volume or a 24-hour volume; (2) the duration between the base year and forecast year; (3) the forecast method; and (4) the number of recessions that occur between the base year and the forecast year.* Based on a small subset of studies with forecasts for both peak hour volume and 24-hour volume, there was a difference in median percent error, with the former being less accurate than the latter ($p = 0.04$). Further, an ANOVA showed that the forecast method and the duration between the base year and the forecast year significantly affected median percent error but only when both factors were considered at the same time ($p = 0.04$). In the short term, a trend-based forecast is slightly less accurate than an activity-based forecast (by about 1 percentage point). However, although both the trend-based and activity-based approaches show a decrease in accuracy when one shifts from a short-term forecast to a long-term forecast, the degradation is greater for activity-based forecasts (which see a change of about 30 percentage points in the median percent error) than for trend-based forecasts (which see a change of about 3 percentage points). These effects are not evident, however, without controlling for the number of recessions ($p = 0.02$).

  That said, there is still some random variation in forecast accuracy. A model based on three (duration, forecast method, and number of recessions) of the four factors explains about 29% of the variation in median percent error. That is, most of the variation in forecast accuracy is either random or based on factors not identified in this study.

RECOMMENDATIONS

1. *VDOT's TMPD should include a recommendation in the Guidebook that when making forecasts for traffic volumes, analysts should consider including some indication of expected forecast error*. Draft language for that recommendation is shown here:

> Because no forecast is likely to be perfect, analysts should consider including some indication of expected forecast error for a given technique. That indication may be based on prior studies that have used similar techniques where one compared the forecast volume to the observed volume. Alternatively, if no such studies are available, the expected error may be based on either of the following two values :
>
> - For studies where an overforecast matters as much as an underforecast, the median absolute percent error for all links within the study may be expected to be 40%.
> - For studies where an overforecast on one link and an underforecast on another link tend to cancel, the median percent error for all links within the study may be expected to be 31%.
>
> Although these two values were selected from Table 11, for some forecasts, it may be appropriate to assume a larger error, and Table 11 may help one make that determination. For example, Table 11 suggests that if one were planning for an almost–worst case scenario, one might anticipate that when one determined the errors for all links in the study, the median of these errors would be 74%. Such an error is in the 95th percentile of studies examined in this report; that is, for most studies, the median percent error would be less than 74%.

Table 11. Expected Percent Errors

Descriptor	Mean Percent Error	Mean Absolute Percent Error	Median Percent Error	Median Absolute Percent Error
Minimum	−20%	1%	−19%	1%
Mean	42%	54%	31%	40%
Median	35%	48%	31%	36%
95th percentile	112%	114%	74%	74%
Maximum	118%	126%	134%	134%

> If it is not desirable to use expected errors based on the studies that provided the basis for Table 11, then an alternative is to present expected errors for individual links based on the literature. One such source is CDM Smith et al. (2014)—also known as NCHRP Report 765—which indicates expected errors of 20% for a 5-year forecast and 42.5% for a 20-year forecast for an existing road, with slightly higher errors of 27.5% and 47.5% for a new road.
>
> The impact of expected percent errors depends on the situation for which the forecast is needed: in some cases, such as for low-volume facilities, it may be the case that even large errors do not materially affect the decision that is based on the forecast. In general, larger forecast errors are observed for forecasting techniques that require data that must be forecast.

2. *Based on the application of the 11 techniques provided in Appendix A, VDOT's TMPD should incorporate four revisions into the next edition of the Guidebook.*

- *For Technique 7,* modify the equation for computing ESALs by replacing the single truck percentage "T" (which appears three times in the equation) with the percent cars, percent single unit trucks, and percent tractor trailers, as was done with Equation A4 in Appendix A. Further, with respect to Technique 7, the *Guidebook* should refer users to the updated guidance provided by VDOT's Materials Division (VDOT, 2014b).

- *For Technique 5,* modify the section discussing seasonal adjustment factors to indicate that the VDOT daily volume count is multiplied, rather than divided, by the seasonal factor in order to estimate an annual ADT and clarify that as part of its count program, VDOT seasonal factors refer to a specific month of the year and day of the week.

- *For Technique 8,* indicate that a spreadsheet for using the Fratar method is available and make this spreadsheet available on the VDOT external website.

- *Add language encouraging transparency in how forecasts are calculated so that the forecasts may be replicated.* For example, as noted in Appendix B for Studies 1 and 3, although the studies provided explanations to indicate how the forecasts were generated, the research team could not replicate the forecasts with the given explanations.

BENEFITS AND IMPLEMENTATION

Benefits

A benefit of implementing Recommendation 1 would be that decision makers could be better positioned to evaluate transportation needs should the forecast diverge from the future observed value. (For example, if a given study had forecasts for several links during the peak hour and it appeared that changing signal timing could accommodate these future volumes, decision makers could use Table 11 to increase the forecast volumes such that the increased forecast volumes differed from the original forecast volumes by a median value of 40%. Then, the decision makers could determine whether changing signal timing could still accommodate such future volumes.)

An immediate benefit of implementing Recommendation 2 would be that transportation planners or other analysts should find it easier to apply Techniques 5, 7, and 8. (Recall that Technique 5 can be used to forecast ADT for a particular season rather than an annual average; Technique 7 can be used to forecast ESALs; and Technique 8 can be used to forecast intersection turning volumes. Thus, if less time is required to apply these techniques, there could be a potential cost savings for forecasters.

Implementation

Recommendation 1 can be implemented by VDOT's TMPD by providing, to the consultant who will be revising the *Guidebook*, the draft language in Recommendation 1 for inclusion in Section 6 or 7 of the *Guidebook.*

Recommendation 2 can be implemented by VDOT's TMPD when the *Guidebook* is updated by providing the following to the consultant who will be performing the update: (1) the Fratar method spreadsheet developed by the research team (provided to one TRP member on March 27, 2015), and (2) the suggested modifications to *Guidebook* Sections 5.3, 5.5, and 4.5 (provided to the TRP on December 1, 2015). This material has been provided to TMPD staff and is also available from the research team. An Executive Review held on June 13, 2016, suggested that about 3 months would be needed to implement these recommendations.

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APPENDIX A

EXAMPLE OF APPLYING EACH TECHNIQUE

Examples of how to apply the 11 techniques are presented herein. (If a study presented a forecast, the technique is reported as Technique 0.) For each technique, two subsections are provided:

1. Application (explains how to apply the technique to develop a forecast).
2. Comparison (explains how to compare the forecast value and the observed value).

Technique 0. Before/After Comparison

Technique 0 refers to the direct comparison of the study predicted volume and the observed volume; no technique was applied by the research team. Each of the 39 studies shows, or implies, a forecast volume for a horizon year. For example, Study 20 developed a forecast for year 2010 by using a regional TDM for the Charlottesville area. The model (U.S. Department of Transportation et al., 1990) shows a volume of 33,592 ADT for one link. However, for the same link, VDOT (2010) shows a volume of 19,000 ADT. Thus Study 20 forecast a higher volume than what was observed for the particular link.

Technique 1. Adjusted Regional Model Outputs

Technique 1, also known as "Post-processing model outputs—daily link volumes forecast adjustments," corrects local errors in the TDM under the premise that for a specific link, if the model's base year link volume is higher than the actual link volume, the forecast year link volume will also be higher than the forecast year actual link volume. The technique is applied for an example from Study 20 of a link with an actual base year ADT of 19,400 that exceeds the modeled base year ADT of 23,717. Accordingly, the modeled forecast year link volume of 28,088 needs to be adjusted. The adjustment process requires three main steps: compute the delta factor and ratio factor for the base year, adjust the forecast by each factor, and compute the average of the adjustments.

Application

1. Compute the delta factor and ratio factor for the base year.

    - The delta factor = modeled ADT – actual ADT = 23,717 – 19,400 = 4,317.
    - The ratio factor = modeled ADT ÷ actual ADT = 23,717 ÷19,400 = 1.22.

2. Adjust the forecast by each factor.

    - The delta factor is subtracted from the forecast such that 28,088 − (+4,317) = 23,771.

    - The forecast is divided by the ratio factor such that 28,088 ÷ (1.22) = 22,975.

3. Compute the average of the adjustments.

   - The average of the adjustments is (23,771 + 22,975) ÷ 2 = 23,373.

Because this technique is also applied if the base year modeled ADT is lower than the base year actual ADT, sign retention in these three steps is essential.

Comparison

Thus the forecast ADT (23,373) may be compared to the observed ADT (19,000). If it were the case that the regional plan had forecast AWDT, the forecast would have been compared to the observed AWDT.

Technique 2. Trend Analysis of Regional Model Outputs

As with Technique 1, Technique 2 is used when a regional TDM is employed. This technique determines the annual rate of growth based on the modeled volume (from the base year to the forecast year) and then applies the growth rate to the existing modeled volume to obtain the forecast year modeled volume. Either a linear growth rate or a compound growth rate may be used. However, in its discussion of Techniques 3 and 4, the *Guidebook* suggested a linear growth rate can be preferable if there are just two data points being used to develop a trend. Since that is the case with Technique 2, a linear growth rate was used. Relative to Technique 1, an advantage of Technique 2 is that it can be applied for any forecast year—not just the forecast year that was used in the TDM. Technique 2 requires two steps: compute the annual growth rate (based on the model), and apply that growth rate to the base year ADT.

Application

As an example, the same link noted in Technique 1 (from Study 20) may be considered where the modeled ADT was 23,717 in base year 1987; the modeled ADT was 28,088 in forecast year 2010; the observed base year ADT was 19,400 in 1987; and a forecast is needed for year 2000 and year 2010.

The modeled growth rate for the entire 23-year period from 1987-2010 is (28,088 − 23,717) ÷ 23,717 = 18.4%. On an annual basis, this yields growth of 18.4%/23 years = 0.8% per year. Accordingly, for interim year 2000, the forecast ADT is 19,400 × (1 + [0.008 × 13]) = 21,418. For forecast year 2010, the forecast ADT is 19,400 × (1 + [0.008 × 23]) = 22,970.

Comparison

Thus for year 2000, the forecast ADT (21,481) may be compared to the observed ADT (19,787), and for year 2010, the forecast ADT (22,970) may be compared to the observed ADT (19,000). As with Technique 1, had it been the case that the regional plan had forecast AWT, the forecast would have been compared to the observed AWT for years 2000 and 2010.

Technique 3. Linear Growth Based on Two Traffic Counts

Technique 3, also known as the "simplistic method" for a "traffic count trend analysis," entails the use of past traffic counts to forecast a future traffic count where a linear change in ADT per year is calculated and then applied to a future year. For example, for a section of Route 3 between Route 301 and Route 205, Study 1 showed that the 1965 ADT was 1,810 and the 1985 ADT was 2,885. A forecast for year 2010 was needed.

Application

Accordingly, from the past, the change in ADT per year is (2,885 − 1,810)/20 years = 53.75/year. Since the 2010 forecast is 25 years after 1985, the 2010 forecast is computed as 1985 ADT + 25 * (Change in ADT per year), or 2,885 + 25 * 53.75 = 4,229.

Because the linear growth rate is based on only two data points, it is sensitive to which two points are selected. For example, for that link it would have been possible to base the calculation on a 1970 ADT (2,540) and a 1986 ADT (3,325), which would yield a forecast of 4,503, which is about a 6% difference from the forecast noted.

Comparison

Thus the forecast ADT (4,229 or 4,503) is compared to the observed ADT (4,887).

Technique 4. Regression Based on Multiple Traffic Counts

As was the case with Technique 3, Technique 4, also known as "least squares regression analysis" for a "traffic count trend analysis," uses historical traffic counts to make a forecast for the future year. However, multiple data points rather than just two are used to make the forecast. For example, for the same segment noted for Technique 3, i.e., a section of Route 3 between Routes 301 and 205 from Study 1, the data shown in Table A1 were available for the period from 1965-1986, and a forecast is needed for year 2010.

Table A1. Historical Average Daily Traffic (ADT) for a Route 3 Between Routes 301 and 205

Year	1965	1970	1975	1980	1985	1986
ADT	1,810	2,540	3,160	3,645	2,885	3,325

Application

The technique of least squares linear regression, where the year is the independent variable and the ADT is the dependent variable, yields Equation A1. Equation A1 can be obtained in three ways: one can perform linear regression by hand as shown in the *Guidebook;* one can obtain this linear regression equation from a software package (in Excel, for instance, one uses the steps Data Analysis/Regression); or one can create a graph of the data in Table A1 and then add a trend line, with the equation, to the chart.

$$\text{ADT} = -115{,}514 + 59.9\ (\text{forecast year}) \qquad \text{[Eq. A1]}$$

For example, for a 2010 forecast year, Equation A1 yields a forecast of 4,885. There is some rounding of the coefficients in Equation A1, but this does not materially affect the results; without any rounding, the exact forecast from Equation A1 is 4,881.

Comparison

Thus the forecast ADT (4,881) is compared to the observed ADT (4,887).

Technique 5. Seasonal Adjustment Factors

According to the *Guidebook*, the seasonal adjustment factor can be used to convert a count taken over a given period of time (say a Tuesday and Wednesday in March) to an ADT; one *divides* the periodic count by the seasonal factor to obtain the ADT (Eq. A2). The process that VDOT uses to obtain ADTs is similar but slightly more detailed and has one key correction. In practice, VDOT obtains an estimate of a yearly volume—an ADT—using Equation A2, where the axle count is multiplied by an annual axle factor (given that different types of vehicles have different numbers of axles) and this is *multiplied* by the seasonal factor as shown in Equation A3. The seasonal factor itself reflects not just a season but rather both a month and day of the week. For example, for a given link in 2014 in August, there are eight factors: one for each day of the week plus one that reflects the month of August alone.

ADT = Seasonal volume/Seasonal factor [Eq. A2]

ADT = (Axle count) × (Annual axle factor) × (Seasonal factor) [Eq. A3]

The rationale for using Equation A3 rather than Equation A2 can be verified for a particular link. For example, as shown in Table A2, for August 18, the axle count (12,998) multiplied by the axle factor (0.4700982) and the seasonal adjustment factor (0.961664) gives an ADT of 5,876. Repeating this process for August 19 gives an ADT of 6,262. Averaging these two values gives the year 2010 ADT of 6,069 reported in VDOT's TMS database (VDOT, undated a).

Table A2. Verification of How Seasonal Adjustment Factors Are Used to Estimate Average Daily Traffic (ADT) for Link 160044

Day	Axle Count[a]	Axle Factor[b]	Seasonal Factor[c]	ADT
Wednesday August 18	12,998	0.4700982	0.961664	5,876
Thursday, August 19	14,497	0.4700982	0.918854	6,262
ADT				6,069

[a] The axle count denotes the raw daily axle counts for that link taken on Wednesday or Thursday.
[b] The axle factor is determined by matching the TMS link id and corresponding factor group number from an internal software application provided by Jones (2014).
[c] The seasonal factor is obtained using the factor group number for a particular day, month, and year (e.g., Wednesday in August in 2010) using the internal software application provided by Jones (2014).

Application

Based on Equation A3, three steps are taken to forecast a seasonal ADT.

- *Step 1. Pick a season for which a count should be forecast*. Based on Table A2, the season that is chosen is a Wednesday and Thursday in August.

- *Step 2. Identify the base year annual axle and seasonal adjustment factors*. Seasonal adjustment factors were likely in existence in 1986; however, the research team could not find documentation indicating what those factors were. In 1998—the closest year to the base year of 1986 where data are available—the Wednesday and Thursday seasonal adjustment factors for August were, respectively, 0.94922981 and 0.9191984.

- *Step 3. Divide the forecast year ADT by the seasonal adjustment factors to obtain a forecast of a seasonal ADT*. For example, in 1986, the forecast ADT for year 2010 was 9,800. Assuming that the seasonal factors used in 1998 were the same as those used in 1986, a forecaster would have expected the average seasonal ADT (for a Wednesday and Thursday in August) to be ½(9800/0.94922981 + 9800/0.9191984) = 0,493.

Comparison

VDOT does not typically report a seasonal ADT but rather an annual ADT. However, it is possible, with Steps 4 and 5, to estimate a seasonal ADT.

- *Step 4. Identify the day and month when a forecast year axle count was taken*. For example, for link 160044, which is the section of Route 3 between Routes 204 and 205 from Study 1, for the forecast year of 2010, actual counts were taken on Wednesday, August 18, and Thursday, August 19, 2010. These counts were 12,998 and 14,497 axles, respectively.

- *Step 5. Multiply by the appropriate forecast year axle adjustment factor to obtain a seasonal ADT*. In 2010, the axle adjustment factor was 0.4700982. Accordingly, the seasonal counts for August 18 (Wednesday) and 19 (Thursday) are (12,998)(0.4700982) = 6,110 ADT and (14,497)(0.4700982) = 6,815. Hence the seasonal ADT (for a Wednesday and Thursday in August) is 6,463. This is the correct observed value against which a forecast should be judged.

Thus the forecast seasonal ADT of 10,493 in Step 3 is compared to the actual seasonal ADT of 6,463 in Step 5.

Technique 6. Peak Hour Link Forecasting

Technique 6 entails multiplying the forecast ADT by the expected proportion of ADT that will occur during the peak hour in order to obtain the peak hour volume. The *Guidebook* noted that this proportion of ADT will be determined from a "diurnal," which it defines as "the curve of the hourly volume flow of the daily traffic volumes." There are, in fact, multiple methods to determine the proportion of ADT that will occur during the peak hour: (1) generate a diurnal from a continuous count station (as suggested in the *Guidebook*); (2) assume the proportion will remain the same in the future as what it is at present; and (3) use values from the literature where such values relate the peak hour factor to the congestion level, for example, Simons (2006).

Application

The 1997 U.S. 15 James Madison Highway Passing Lane Study (Study 3) used the second method, i.e., presuming that the K-factor, which was 10% in 1996, would retain the same value in the forecast year of 2016. Since the forecast year ADT had been projected to grow from 7,160 to 10,360, the study forecast that the peak hour volume would be 10% of 10,360, which was 1,036. [Note that the study refers to a 15.5-mile section of U.S. 15; in fact, VDOT has counts on six sections of Route 15. Accordingly, it was necessary to convert these six counts to a single value for the entire section using an approach similar to that reported for Equation 1 in the body of this report.]

Although the U.S. 15 study followed the second method for determining the K-factor (i.e., assume it will remain constant), an option would have been to examine how this K-factor might decrease given that the peak hour ADT was set to increase from 716 to 1,036. Although 2016 data are not yet available, 2014 data are available, indicating that the actual peak hour volume was 548, with an aggregate K-factor of 0.0916. Given that the directional factors for this location vary between 0.517 and 0.591 for the six sections that comprise this 15.5-mile segment, the largest directional volume is only about 345 vehicles. Given a typical capacity of 1,700 passenger cars per hour (which would be similar to 1,700 vehicles, presuming a relatively low truck percentage) for a given direction (Garber and Hoel, 2015), one would probably not have expected any peak hour spreading because of congestion. Thus the use of the second method (i.e., assuming the peak hour factor to remain constant) would appear reasonable had it been known in 1997 that the ADT would be 5,985 rather than the forecast value of 10,360.

Comparison

Thus the forecast peak hour volume (1,036) is compared to the actual peak hour volume (548). A complication is that the actual forecast year for the study is 2016 whereas the observed volume is for year 2014. Because the study noted that the forecast ADT presumed a growth rate of 2% per year, it could be argued that the forecast ADT for year 2014 should be slightly lower (998 to 1,004).

[This range results because of a secondary but very minor complication. A 2% annual increase in traffic from a 1996 value of 7,160 cannot give a value of 10,360 in 2016. If a linear increase in traffic is presumed each year as is the case with Technique 3, the annual percent increase would be 2.2344%. If a compound increase is presumed each year, as is the case with interest, the annual percent increase would be 1.8644%. For year 2014, these two methods would give a value of either 998 or 1004—a difference that is negligible.]

Technique 7. ESAL Estimation

The equation given in the *Guidebook* for computing ESALs was modified such that the variable "T," which is reported as being "percent trucks," is corrected in order to be "percent trucks by type." Although the *Guidebook* refers to two truck types as "MT" and "HT" for "medium trucks or single-unit trucks" and "heavy trucks or tractor-trailer combination units," VDOT (2014b) refers only to single unit trucks or tractor trailer trucks, so that terminology was used here. Further, as these equations were applied to two-way links, the directionality factor was set to 1.0. The modified equation is shown as Equation A4 where ESAL yields the equivalent single-axle load for the pavement.

$$\begin{aligned} ESAL = {} & (ADT)\,(L_f)\,(365)\,[(E_{f,\ car})(\text{Percent cars}) \\ & + (\text{Percent single unit trucks})(E_{f,\ \text{single unit truck}}) \\ & + (\text{Percent tractor trailer trucks})(E_{f,\ \text{tractor trailer truck}})] \end{aligned} \qquad \text{[Eq. A4]}$$

The variables in Equation A4 are defined as follows:

ADT is the average daily traffic for the forecast year.

L_f is shown in the *Guidebook* as "Lane factor, considering distribution of traffic flow by lane" and is described in VDOT (2003) as the "lane distribution factor," which has a value of 1, 0.9, 0.7, or 0.6 depending on whether there are 1, 2, 3, or 4 or more lanes per direction.

E_f (equivalency factor) was initially determined based on a review of Babish (2009) as noted in the *Guidebook*. However, these factors were updated by VDOT (2014b) as follows: for rigid pavements, 0.0003 (cars), 0.59 (single unit trucks), and 1.59 (for tractor trailer trucks); for flexible pavements, 0.0002 (cars), 0.46 (single unit trucks), and 1.05 (tractor trailer trucks).

Single unit trucks, as reported by Smith and Diefenderfer (2009), are Vehicle Classifications 4 through 7, and thus buses are included therein.

Tractor trailer trucks, as reported by Smith and Diefenderfer (2009), are Vehicle Classifications 8 through 13.

Cars are considered to be Vehicle Classes 2 and 3 (automobiles and pickup trucks). Motorcycles (Class 1) are not explicitly included in Equation A4; however, if a given data source does not explicitly exclude motorcycles from vehicle counts, motorcycles will be included with the "car" term.

Equation A4 is an approximation; for instance, as pointed out by Diefenderfer (2015), it is possible for a single unit truck (such as a loaded five-axle Class 7 vehicle) to be heavier than a tractor trailer combination unit (such as a Class 9 single trailer).

Application

As an example of computing ESALs, Study 1 may be considered. In this study, the year 2010 ADT forecast for Route 3 between Route 301 and Route 205 Oak Grove was 5,340. No truck percentages were forecast; however, the most recent truck percentage given in the study was 8.8%, with 91.2% of vehicles being cars. The corridor study defined such trucks as "heavy trucks (6-tired vehicles and larger),"which would include both single unit trucks and tractor trailers. Although the study did not contain any other data that would inform a truck percentage, the most recent counts the research team could find that would have been available at that time (Virginia Department of Highways and Transportation [VDH&T], 1986) indicated that, for this same link (Route 301 to Route 205) there was a total of 2,885 vehicles, distributed as follows:

- 1,910 passenger cars (considered by the research team to be Class 2)
- 720 2-axle 4-tire single unit trucks (considered by the research team to be Class 3)
- 125 single-unit trucks with 2 or 3 axles and 6, 8, or 10 tires (considered by the research team to be a single unit truck in Class 5, 6, or 7)
- 120 "trailer trucks" (considered by the research team to be tractor trailers)
- 10 buses (considered by the research team to be Class 4).

Interestingly, these data show the source of the 8.8% "heavy trucks," given that 120 tractor trailers, 10 buses, and 125 single unit trucks with 6, 8, or 10 tires yields 255 trucks and is thus 8.8% of the total of 2,885 vehicles. More important, they show that in 1985 approximately 53% of these "heavy trucks" were single unit trucks (Classes 4-7) and 47% were tractor trailers. A shapefile provided by VDOT Maintenance staff (Stickel, 2015) indicated that asphalt (a flexible pavement) was used for this section of Route 3. There is only one lane in each direction, so the lane factor L_f is 1. Accordingly, the forecast ESALs from Equation A4 are computed as 126,818 in year 2010 (see Eq. A5).

$$\text{ESALs} = (5{,}340)(1)(365)[(0.0002)(91.2\%) + (0.46)(4.7\%) + (1.05)(4.1\%)] \quad \text{[Eq. A5]}$$

Comparison

The actual ESALs are 99,858 and are computed as shown in Equation A6, given that in year 2010 the ADT was 4,887 with 93% cars, 3% single unit trucks and buses, and 4% tractor trailers.

$$\text{ESALs} = (4{,}887)(1)(365)[(0.0002)(93\%) + (0.46)(3\%) + (1.05)(4\%)] \quad \text{[Eq. A6]}$$

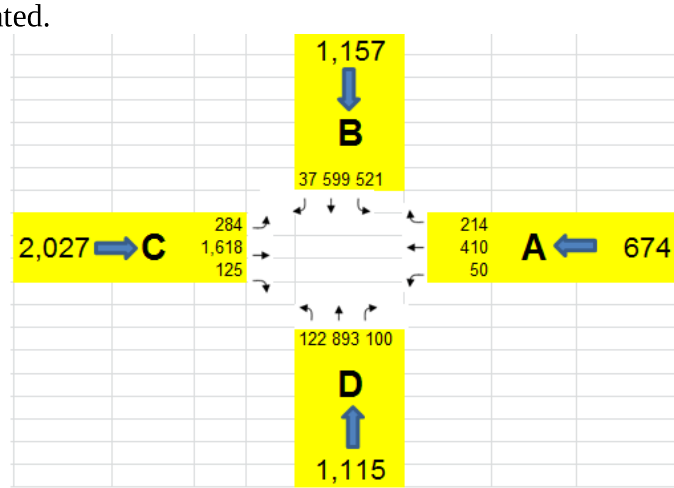
Thus the forecast ESALs (126,818) are compared to the actual ESALs (99,858).

Technique 8. Fratar Method

The Fratar method iteratively estimates forecast year intersection turning movements using two pieces of information: base year intersection turning movements and forecast year link volumes. From these, forecast year turning movements are forecast. For example, for a four-way intersection, the input data are the 12 base year turning movements (see left of Figure A1) and the eight forecasts of link volumes at each approach (see right of Figure A1). Based on these data, the Fratar method will provide the forecast year turning movements at the intersection. As pointed out in the *Guidebook*, the Fratar method is well documented in the literature, although there are variations on how the technique can be applied (see, for example, Meyer and Miller, 2013, or Garber and Hoel, 2015). The Fratar method is iterative and is best coded in a spreadsheet; a spreadsheet was developed for this purpose by the research team and was provided to VDOT's TMPD staff following a meeting with the TRP on March 27, 2015.

Application

From Study 37, example data for the morning peak intersection of Old Keene Mill Road (Route 644) and Rolling Road (Route 638) are shown on the left in Figure A1, where westbound traffic on Old Keene Mill Road enters the intersection at Approach A and exits the intersection at Approach B (if right turn), Approach C (if straight), or Approach D (if left turn). Data for the base year of 2005 are shown. The right of Figure A1 shows a possible link volume forecast for the year 2012; for example, westbound Old Keene Mill Road traffic is forecast to change from 674 (in 2005) to 882 (in 2012). "Possible" is used here because at the time, forecasts were not generated.



Approach	Base	Forecast
Enter A	674	882
Exit A	2,239	1,744
Enter B	1,157	1,091
Exit B	1,391	1,124
Enter C	2,027	1,501
Exit C	569	664
Enter D	1,115	875
Exit D	774	817

Figure A1. Base Year Turning Movements (Left) and Forecasts of Link Volumes (Right). Only the entering volumes are shown on the left. For example: In the base year, there are 214 + 410 + 50 = 674 vehicles entering the intersection at Approach A, and there are 521 + 1,618 + 100 = 2,239 vehicles exiting the intersection at Approach A. In the forecast year, the volumes entering and exiting the intersection at Approach A are forecast to change to 882 and 1,744, respectively.

The approach followed in the spreadsheet is identical to the description provided in the *Guidebook*. In sum, the spreadsheet computes a ratio between forecast year link volumes and base year link volumes (see right of Figure A1) for each row and column (see Figure A2). These ratios generate a row factor and a column factor. One application of the Fratar method is to multiply each cell by its row factor and then to multiply each cell by its column factor; this process is then repeated several times until the internal cells (see top of Figure A2) do not change. Another application of the Fratar method is to compute a row factor and column factor, compute the average of these two factors, multiply this average by the appropriate cell, and then repeat this process several times until the internal cells do not change (see bottom of Figure A2). The two methods yield almost identical results, although Method 1 required only 8 iterations (until each row total and column total was within 1 of the desired total) compared to 36 iterations for Method 2.

Method 1	A exit	B exit	C exit	D exit	Total
A enter	0	260	535	87	882
B enter	445	0	29	618	1,091
C enter	1,209	180	0	113	1,501
D enter	90	684	100	0	875
Total	1,744	1,124	664	817	0

Method 2	A exit	B exit	C exit	D exit	Total
A enter	0	263	533	85	881
B enter	446	0	29	617	1,092
C enter	1,207	180	0	114	1,502
D enter	90	681	103	0	874
Total	1,743	1,125	665	816	0

Figure A2. Forecasts Based on the Fratar Method. Example: Methods 1 and 2 forecast that the number of vehicles entering the intersection at Approach A and exiting at Approach B—hence right turns from Approach A—will be 260 and 263, respectively, vehicles in the forecast year.

Comparison

The 12 forecast turning movements (based on Method 1 of the Fratar method at the top of Figure A2) may be compared to the 12 observed turning movements collected at the intersection in 2012. Figure A3 makes this comparison. For example, whereas 260 vehicles were forecast to turn right from Approach A to Approach B, 285 vehicles were observed turning right from Approach A to Approach B.

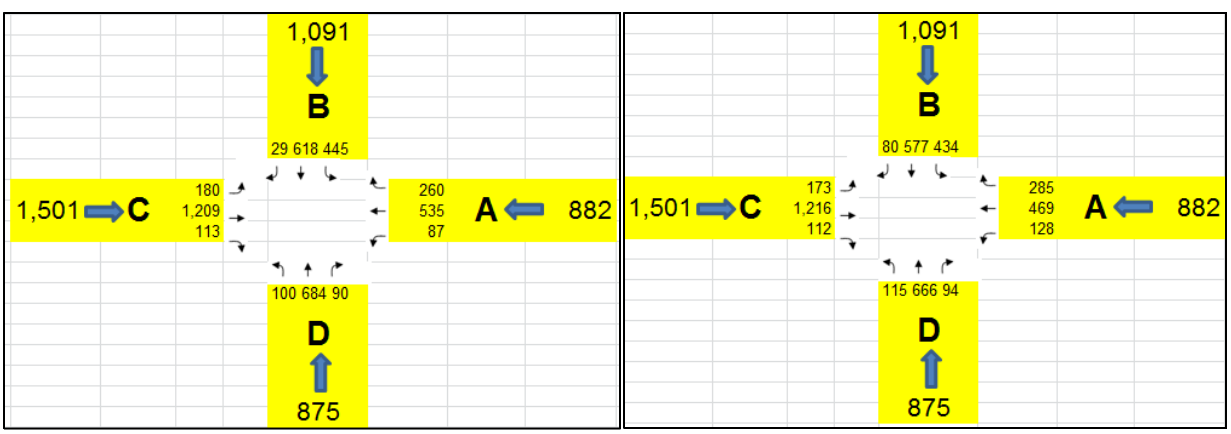


Figure A3. Forecast Turning Movements (Left) and Observed Turning Movements (Right)

Technique 9. Population-Based Forecasts

The Route 3 Corridor Study (VDOT, 1988a) noted: "Since the Route 3 Corridor serves a fluctuating population, the only reliable determinant of the future traffic is the historical traffic data." The study provided base year (1985) and forecast year (2010) populations. A principle of the ITE factoring approach in the *Guidebook* was that demand for transportation is based on land development. A modification to this approach is simply to apply the ratio of forecast population divided by current population to the existing (1985) ADT that was available at the time the study was conducted. To be clear, this technique is not in the *Guidebook* but rather is a modification considered by the research team.

Application

For example, in 1985, the forecast for 2010 population was 77,900 for the six counties in the study area, compared to an existing 1985 population of 61,100. Because population increased by 27.5%, one may then assume each link will see its volume increase by 27.5%. Accordingly, for the aforementioned segment of Route 3 between Routes 301 and Route 205, the 1985 ADT of 2,885 may be increased by 27.5% to yield a 2010 forecast of 3,678.

Comparison

The forecast of 3,678 ADT may be compared to the observed value of 4,887 ADT.

Technique 10. ITE-Based Factoring

Contrary to Techniques 3 and 4, ITE-based factoring is not based on previous traffic growth at a given location. Rather, as is the case with Technique 9, Technique 10 forecasts travel demand based on activity. Whereas Technique 9 used population growth to indicate activity, Technique 10 uses anticipated land development to forecast activity. Detailed procedures for applying Technique 10 are not given in the *Guidebook*; rather, key topics are listed (e.g., determine trip generation rates, trip reductions for multi-use developments, and the amount of additional traffic generated at the site). However, a detailed nine-step procedure that more fully explains these topics is provided in Chapter 7 of ITE's *Trip Generation Handbook* (ITE, 2004). That procedure is illustrated in the subsections that follow.

Application

A proposed development is a wholesale club with 114,576 ft^2 and 12 fueling stations, where the concern is additional traffic generated during the evening peak hour.

1. *Identify land use types, their corresponding ITE land use codes, and sizes.* The two land use types are Discount Club (Code 857 with 114.6 square feet [in thousands]) and gasoline stations (Code 944 and 12 fueling positions).

2. *Pick a time period for analysis.* The analysis time period is evening peak hour of adjacent street traffic.

3. *Compute baseline trip generation for individual land uses.* For Code 857, ITE (2008) indicates that the average rate is 4.24 trips/1,000 ft^2. For Code 944, the average rate is 13.87 trips/fueling position. Accordingly, the discount club will generate (4.24 * 114.6) = 486 trips, and the fueling station will generate 13.87 * 12 = 166 trips, for a total of 652 trips.

   As ITE (2008) shows 50% of trips entering and 50% exiting for both land uses, the discount club will generate 50%(486) = 243 entering trips, and the fueling station will generate 50%(166) = 83 entering trips. The number of exiting trips is identical.

4. *Estimate anticipated internal capture rate between each pair of land uses.* If two land uses that might share trips (e.g., a person visiting the discount club might also stop for gas), summing all trips from Step 3 may result in overestimation of the net number of trips generated by the site. Tables 7.1 and 7.2 of ITE (2004) provide internal capture rates between land uses based on their categorization as office, retail, or residential. If both land uses are treated as retail, ITE (2004) suggests that 20% is an appropriate rate, meaning that the trips in Step 3 may be reduced by this amount. [Note that although gasoline stations were considered to be in the "service" land use category by ITE (2008), they were considered to be in the "retail" category by DKS Associates (2015).]

5. *Estimate "unconstrained demand" volume by direction.* The directional trips from Step 3 are multiplied by the percentage in Step 4. For example, *trips from the discount club to the fueling station* are computed as 243 exiting trips from the discount club × 20% = 49 trips and also as 83 entering trips to the fueling station × 20% = 17 trips. (Although 20% is used in both calculations as these are both retail sites, it is possible for the percentages to differ if one land use is retail and the other is office or commercial.)

6. *Estimate "balanced demand" volume by direction.* As shown in Step 5, a single direction of travel from Land Use A to Land Use B will generate two reductions. For each such direction, select the lower value to be recorded as the "balance." In Step 5, trips from the discount club to the fueling station were computed as both 49 trips and 17 trips; therefore, the controlling value is 17 internal trips.

7. *Estimate total internal trips to/from multi-use development land uses.* The total internal trips are 34, with 17 from the discount club to the fueling station and 17 from the fueling station to the discount club. Overall, 7% of the discount club trips (34 of 486) are internal to the multi-use development.

8. *Estimate total external trips for each land use.* The external trip volumes for each land use are determined by subtracting internal trips from total trips. Thus for the discount club, there are 243 − 17 = 226 trips external entering trips and 226 external exiting trips. For the fueling station, there are (83 − 17) = 66 external entering trips and 66 external exiting trips.

9. *Calculate internal capture rate and total external trip generation for multi-use site.* From Step 8, the entering volume estimate of 292 peak hour trips is the sum of the external trips entering the discount club (226 trips) and the fueling station (66 trips). Since the exiting trips have the same value, the net external volume for the multi-use site is (292 + 292) = 584 trips. Compared to the 652 trips in Step 3, the value of 584 trips represents a trip reduction of 10%. Figure A4 summarizes the calculations from Steps 3 through 9 based on ITE (2004).

Land use A (Discount Club)
ITE Land USE CODE 857 (Page 1630)
Size: 114,576 square feet GLA
Time: Weekday PM peak hour of adjacent Traffic

	Total	Internal	External
Enter	243	17	226
Exit	243	17	226
Total	486	34	452
%	100	7%	93%

Exit to External 226
Enter from External 226

Demand	20%	49
Balance	20%	17
	17	

Demand	20%	49
Balance	20%	17
	17	

Land use B (Gasoline Stations)
ITE Land USE CODE 944 (Page 1,891)
Size: 12 vehicle fueling positions
Time: Weekday PM peak hour of adjacent Traffic

	Total	Internal	External
Enter	83	17	66
Exit	83	17	66
Total	166	34	132
%	100	20%	80%

Exit to External 66
Enter from External 66

Net External Trips for Multi-Use Development				
	Land Use A	Land Use B	Total	
Enter	226	66	292	
Exit	226	66	292	
Total	452	132	584	Internal Capture
Single-Use Trip Gen. Est.	486	166	652	10%

Figure A4. Multi-Use-Trip Generation Calculation (adapted from ITE, 2004)

Comparison

The study (Vanasse Hangen Brustlin, Inc. [VHB], 2007) projected the volume for 2009 at the adjacent street and generated a site volume considering BJ's Wholesale Club would be built by 2009. The forecast volume was obtained by taking the summation of the volume if no development was built in 2009 and "site volume" generated by the new development. For example, the study forecast peak hour volume for Starling Drive, a roadway along the club, to be 828 in 2009. Since the study showed turning movement at various intersections, all the northbound (293), southbound (487), and turning volumes (0, 12, 12, and 24) to and from the counter location were added to determine the total volume of 828. Based on the study, site volumes were generated by some percentage of the total entering traffic of 292, derived from the ITE trip generation described. The total site volume (roughly 264) was determined by adding two directional (40%) and two turning (5%) volumes. Therefore, the total peak hour volume projected by the study was (828 + 264) = 1,092 for Starling Drive. The forecast peak hour volume for 2009 may be compared to the observed peak hour volume for 2010, where the latter was provided by Henrico County staff (Smidler, 2015).

Technique 11. Traffic Shift Method for Corridors

Technique 11 forecasts the flow of vehicles between two alternative (often parallel) routes. Although it was not a technique described in the *Guidebook*, the traffic shift method for corridors was considered in this study as a forecasting technique. Technique 11 was taken from Martin and McGuckin (1998) and is used to predict the effects of an improvement on a corridor. It is based on utility theory, where an improvement that reduces travel time for a given route A will reduce the volume on alternative route B.

Application

As an example, two alternative routes may be considered: I-64 (between J. Clyde Morris Boulevard and the border with the City of Hampton) and U.S. 60 (between J. Clyde Morris Boulevard and Harpersville Road in Newport News, Virginia). In 2006, I-64 was widened from six to eight lanes between Bland Boulevard and I-664. The widening included two additional HOV lanes on the eastbound and westbound facilities. I-64 and U.S. 60 were reviewed in 2001, prior to roadway improvements, and in 2007 following the lane widening. Tables A3 and A4 show the existing and observed conditions in 2001 and 2007. (Table A4 does not repeat certain columns from Table A3 that did not change.)

Table A3. 2001 Existing Conditions (Base Year)

Link	From	To	Capacity per Lane	No. of Lanes	Capacity Total	Length (miles)	Average Daily Traffic	Peak Hour Volume	Free Flow Speed
I-64	J. Clyde Morris Blvd.	Hampton City Line	2,400	3	7200	1.06	74,000	6,600	73.5
U.S. 60	J. Clyde Morris Blvd.	Harpersville Rd.	810 used	3	2430	1.07	30,000	3100	47

Table A4. 2007 Observed Conditions (Forecast Year)

Link	No. of Lanes	Capacity Total	Length (miles)	Average Daily Traffic	K-Factor	Peak Hour Volume	Free Flow Speed
I-64	4	9,600	1.06	71,000	0.074	5,254	73.5
U.S. 60	3	2,430	1.07	24,000	0.097	2,328	47

If an analyst wanted to forecast how the addition of the HOV lanes would affect the traffic volumes on I-64 and U.S. 60, the analyst would use Equations A7 through A18 to apply the traffic shift method for corridors.

Computing speed from the Bureau of Public Roads (BPR) curve

$$T_c = T_f \times \left(1 + \alpha \times \left(\frac{v}{c}\right)^{\beta}\right) \quad \text{[Eq. A7]}$$

where T_c represents the congestion time, T_f represents the free flow time, v represents volume, c represents capacity, and α and β represent BPR coefficients (Martin and McGuckin, 1998). In order to compute the congestion time (T_c), one would attain the free flow speed from the VDOT Statewide Planning System (VDOT, 2015) and compute the free flow time (T_f) for I-64 and U.S. 60. (Note that for the purposes of this report the "Statewide Planning System" [SPS] is a separate application from the "Statewide Highway Planning System" [SHiPS] mentioned in Study 25.)

Equations A8 through A10 show how to compute free flow speed.

$$T_f = \frac{\text{Length}}{\text{Free Flow Speed}} \times (60) \quad \text{[Eq. A8]}$$

I-64

$$T_f = \left(\frac{1.06 \text{ miles}}{73.5 \text{ miles per hour}}\right) \times (60) = 0.87 \text{ minutes} \quad \text{[Eq. A9]}$$

U.S. 60

$$T_f = \left(\frac{1.07 \text{ miles}}{47 \text{ miles per hour}}\right) \times (60) = 1.37 \text{ minutes} \quad \text{[Eq. A10]}$$

After determining the free flow time, one would insert the remaining values back into the original equation. For I-64, one would use the BPR coefficient for a freeway at 70 mph for both α and β. For U.S. 60, Klieman et al. (2011) provided α and β coefficients for a facility listed as "Mixed Urban Major Arterial." Equations A11 and A12 show these computations.

I-64

$$T_c = 0.87 \times \left(1 + 0.88 \times \left(\frac{6600}{7400}\right)^{9.8}\right) = 1.19 \text{ minutes} \quad \text{[Eq. A11]}$$

U.S. 60

$$T_c = 1.37 \times \left(1 + 0.73 \times \left(\frac{3100}{2430}\right)^{3}\right) = 3.44 \text{ minutes} \quad \text{[Eq. A12]}$$

Equations A13 and A14 show how to determine the diversion parameter, θ. The diversion parameter quantifies the effect of travel time on choice based on existing conditions. For example, if θ = 0, travel time has no impact on choice, whereas a large value of θ would mean that travel time has a large impact on choice.

$$\theta = \frac{\ln\frac{V_{US60}}{V_{I64}}}{t_{I64} - t_{US60}}$$ [Eq. A13]

$$\theta = \frac{\ln\frac{3100}{6600}}{1.19 - 3.44} = 0.336$$ [Eq. A14]

The improvement being made to I-64 is the addition of a lane; therefore, the BPR function is used to evaluate how an increase in capacity should reduce travel time. Accordingly, Equation A11 is applied with one modification: the capacity is changed from 7,200 to 9,600. Thus T_c for I-64 after the improvement is computed via Equation A15.

I-64 Widened

$$T_c = 0.87 \times \left(1 + 0.88 \times \left(\frac{6600}{9600}\right)^{9.8}\right) = 0.88 \text{ minutes}$$ [Eq. A15]

Finally, Equations A16 through A20 are used to calculate the forecast volumes. V_{I64} represents the volume on the faster router (I-64), and V_{US60} represents the volume on the alternate route (U.S. 60). Equation A16 may be used to estimate the new volumes under two scenarios. Scenario 1 presumes one does not expect the total volume from I-64 and U.S. 60 to change from 2001 to 2007 (Eqs. A17 throughA18). Scenario 2 presumes one does know the total I-64 and U.S. 60 volume in 2007 but does not know how these volumes will be split between the two alternatives (Eqs. A19 through A20).

$$V_{I64} = \frac{1}{1 + e^{\theta\,(t_{I64} - t_{US60})}} \times (V_T)$$ [Eq. A16]

Scenario 1: The total volume in 2007 is assumed to be the same as 2001.

I-64

$$V_{I64} = \frac{1}{1 + e^{0.335(0.88 - 3.44)}} \times (9700) = 6{,}812$$ [Eq. A17]

U.S. 60

$$V_{US60} = V_T - V_{I64}$$ [Eq. A18]

$$V_{US60} = 9{,}700 - 6{,}812 = 2{,}888$$

In Scenario 1, the total volume is not known and it is not clear how the volumes were divided between the two roads. The forecast volume for I-64 is 6,812, and the observed volume is 5,254 (see Table A4). For U.S. 60, the forecast volume was 2,888 and the observed volume is 2,328.

Scenario 2: The total volume in 2007 is known to be 7,582.

In Scenario 2, the total volume is known (7,582), but how this volume is divided between the two routes is not known.

I-64

$$V_{I64} = \frac{1}{1+e^{0.335}(3.44-0.88)} \times (7582) = 5325 \quad \text{[Eq. A19]}$$

U.S. 60

$$V_{US60} = 7582 - 5325 = 2257 \quad \text{[Eq. A20]}$$

In Scenario 2, the sum of the two volumes changes between the initial year and the year after the roadway improvement. In this scenario, I-64 would have a forecast volume of 5,325 and Route 60 would have a forecast volume of 2,257. Table A5 shows how the forecast volume compares to the observed volumes in both scenarios.

Table A5. Error Statistics for Traffic Shift Method for Corridors[a]

Scenario	Link	Forecast Volume (2007)	Observed Volume (2007)	Error	Percent Error	Absolute Percent Error	Mean Absolute Percent Error
Total volume is assumed to be the same as in 2001	I-64	6,812	5,254	1,558	30%	30%	27%
	U.S. 60	2,888	2,328	560	24%	24%	
Total volume for 2007 is known	I-64	5,325	5,254	71	1%	1%	2%
	U.S. 60	2,257	2,328	-71	-3 %	3%	

[a] Calculations were performed by applying the method given in Martin and McGuckin (1998) to two alternative routes in Virginia, i.e., between J. Clyde Morris Boulevard in Newport News and the City of Hampton (for I-64) and between J. Clyde Morris Boulevard and Harpersville Road (for U.S. 60), based on information known in 2001 for a forecast year of 2007. Speeds were forecast from parameters for the Bureau of Public Roads volume-delay function as reported by Martin and McGuckin (1998) and Klieman et al. (2011); capacities were obtained from Virginia's Statewide Planning System (VDOT, 2015).

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APPENDIX B

SUMMARY OF ASSUMPTIONS MADE BY THE RESEARCH TEAM FOR THE VIRGINIA STUDIES

Detailed assumptions made by the research team for each study are available from the research team; a summary of assumptions for each of the 39 studies shown in Table 2 is presented here. Assumptions varied for each study but included topics such as classifying the forecast method for the study; determining what was built (for studies that had multiple forecasts depending on which improvements were constructed); connecting the forecast year (from the study) to the observed year (based on available data); and other factors that might have contributed to forecast error. The studies are numbered from 1 to 39 with there being a Study 24a, 24b, and 24c.

1. *The Route 3 Corridor Study* (VDOT, 1988a) forecast the 2010 ADT of Route 3 from U.S. 301 to State Route 14 in order to assess immediate and future improvements in the corridor. This 88.5-mile corridor was divided into 19 segments, or links, each with its own forecast ADT. The study noted that the forecast was based on previous traffic trends; however, the research team could not replicate the forecast. The study proposed approximately 50 improvements, but the forecast given was independent of any improvements. Logically, however, one would expect that the extent to which the improvements were made would affect the forecast. (For example, the study suggested that at a point where the road is signed as both Route 3 and Route 33, Route 33 could be relocated and Route 3 could be widened from two to four lanes that in the future. However, this had not happened as of 2015.) The original forecast, as well as the application of Techniques 3, 4 and 9, which are discussed in Appendix A, was evaluated for this corridor by the research team. The link "Warsaw to Route 360 South of Warsaw" showed consistently high error with every technique by approximately 300%. When the study was published, this link was where Route 3 and Route 360 converged for about 1 mile. At some point afterward, the road segment was reconstructed such that Route 360 no longer converged with Route 3 for a time, causing a drastic decrease of volume on the segment. When the "Warsaw to Route 360 South of Warsaw" link was omitted from error analysis, the absolute mean percentage error fell from 61% to 43% for the original study and for the techniques applied by the research team from 35% to 18% for Technique 3, from 39% to 22% for Technique 4, and from 29% to 15% for Technique 9.

2. *The George P. Coleman Bridge Financial Alternatives Study* (VDOT, 1989a) forecast the 2010 ADT for the Coleman Bridge under different build alternatives. The research team thinks that the Alternative 12A, which is the reconstruction of the Coleman Bridge, represents the actual scenario based on a review of the study and Kemper (1989). The method for developing this forecast was not stated in the study, except that tolls of $1.00 would reduce traffic by 5% whereas tolls of $0.75 or less would not affect traffic volumes (VDOT, 1989a). The research team noted three critical assumptions in order to compare forecast and observed volume. The first regarded whether "average peak flow" in the study denotes travel in both directions or travel in one direction. If the 2,970 represented travel in one direction, the resultant volume/capacity ratio would be close to 1.0 (e.g., 2,970/3,600 =

0.83) based on an idealized capacity of 3,600 vehicles per hour in one direction. By contrast, if the value represents both directions, the volume/capacity ratio would be considerably lower—perhaps as low as 0.6—and would correspond to a higher LOS. Thus it is assumed by the research team that the 2,970 likely represents travel in one direction as Scenario 12A yielded LOS E (VDOT, 1989a). The second assumption regarded whether or not to apply a 5% reduction to the forecast associated because the study noted that for tolls under $1, the volume should drop by 5%. Although large vehicles (3 or 4 axles) had a toll $1 or more, commuter vehicles had a toll of $0.85 (if E-ZPass) or $2.00 (if cash) as of 2012 (Sabo and Gillard, 2012). The third assumption regarded how to define the base year. An argument could be made for 1982, i.e., the last year that volumes were available for a separate study (VDH&T, 1984d) that supports the forecasts made by VDOT (1989a), or 1986, the last year that volumes were available for this study (VDOT, 1989a).

3. *The U.S. 15 James Madison Highway Passing Lane Study* (UMA Engineering, Inc., 1997) provided a volume forecast for a single section of two-lane road (one lane in each direction) from a base year of 1996 to a forecast year of 2016. Three assumptions were made by the research team in order to examine ADT. The first assumption was that the 2014 observed volume (the most recent volume available) is presumed to be similar to what will be the 2016 observed volume. The second assumption was that a single observed volume for the entire section could be obtained by aggregating the observed volumes for the individual subsections. That is, the single section for which the volume forecast is 15.5 miles long; in practice, this represents six discrete sections of road. The weighted actual ADT (in 2014), computed using Equation 1 in the body of this report, is 5,985, where individual sections show ADTs ranging from 5,300 to 7,700. (The sections are of unequal length such that the 7,700 figure reflects 0.39 miles of the corridor and the 5,300 section reflects 5.1 miles of the corridor.) As explained in the discussion of Technique 6 in Appendix A, neither assumption appears to affect substantially the finding that the forecast ADT (of 10,360) is materially higher than the observed ADT (of 5,985), although the magnitude of the error can vary, depending on which assumption is chosen, from 30% to 96%. A third assumption, also discussed with regard to Technique 6 in Appendix A, is whether the proportion of 24-hour traffic that occurs during the peak hour will change or remain constant (when this proportion decreases because of congestion, the phenomenon is known as peak spreading, meaning that a greater proportion of motorists are choosing to travel outside the peak hour). Although the study made no mention of peak spreading and the K-factor is assumed to remain constant at 0.10, the forecast error for the peak hour is computed by the research team as the difference between the forecast peak hour volume (1,036) and the observed peak hour volume (548), which showed a slightly lower K-factor of 0.092. The study provided a forecast for an ADT and a peak hour volume (referred to as a DHV); however, Table 3 in the body if this report shows the forecast for ADT.

4. *The Colonial Heights Thoroughfare Plan* (Virginia Department of Highways, 1970) recommended improvements, such as widening the Boulevard (Route 1 and 301) between the Appomattox River Bridge and the Temple Avenue to four lanes. The study had a base year of 1966 and a forecast year of 1985 and appeared to use a TDM, with the study noting: "The basis used in the projection of future travel was the analysis of the relationship of existing trips and socioeconomic data and the forecast of the socio-economic parameters for the year

1985." Although 1985 observed counts (against which 1985 forecasts could be compared) enabled one to compare the accuracy of forecasts for primary routes, secondary and city-maintained observed counts were not recorded by VDOT during 1985. Such secondary and city observed volumes were provided by Dunnavant (2016a) and reflected the 24-hour urban traffic count program for the city of Colonial Heights in 1987. (Those 1987 observed volumes were thus a surrogate for 1985 observed volumes.)

5. *The York River Crossing Travel Demand Study* (TransCore and Buchart-Horn, Inc., 2000) was conducted to forecast demand for a new upriver crossing on the York River west of the existing George P. Coleman Bridge. The Hampton Roads Planning District Commission Year 2018 Transportation Model (which was implemented using the MINUTP software package [base year of 1990]) gave forecasts for different scenarios with and without an upriver crossing, a four-lane or six-lane Route 17, and different toll options for the Coleman Bridge. Based on the existing bridge on the York River (which can be detected in VDOT's GIS Integrator [VDOT, 2016a]), the existing number of lanes for Route 17 from the Statewide Planning System (VDOT, 2015), and a description of the existing toll facility (VDOT, 2016b), the research team thinks that Base Model B is the alternative that was built. Although the study provided a forecast for year 2018, a forecast for year 2014 by linear interpolation between 1999 and 2018 was used for a single link given in the alternative labeled Scenario 5. That is, in Scenario 5, the volume for U.S. 17 was 29,000 ADT for 1999 and 51,100 ADT for 2018. Thus the year 2014 forecast was found to be 46,447 ADT by linear interpolation such that the 2014 volume was 90.89% of the 2018 forecast. For the rest of the links, however, the 1999 volume was not given' rather, only the 2018 forecast was given for the Base Model B alternative." (See Study 37 for a detailed example of linear interpolation.) Accordingly, the 2014 forecasts were determined by multiplying the 2018 forecasts by 90.89%. In short, the percent increase for the Scenario 5 alternative was applied to the Base Model B alternative assuming that traffic growth from 2014 to 2018 would be the same for these two design alternatives. (Finally, it was assumed that ADT was forecast, as the terminology "average annual daily traffic" was used in the study. However, it is possible that because base year volumes were collected during the week, the study sought to forecast AWT.)

6. *The Interstate 66 HOV Feasibility Study* (Post et al., 1986) forecast I-66 volume between the U.S. 29 Haymarket Exit and I-495 based on a TDM and had two complications: one pertaining to the alternative, and one pertaining to the DHV (which was treated by the research team as a peak hour volume). The 2010 A.M. peak hour eastbound and westbound volumes were forecast for five alternatives, including the no-build option. The alternatives showed different operational features, such as concurrent flow for HOV-3 and HOV-4; separate, reversible flow for HOV-3 with and without access to I-495; and no HOV lanes. However, no alternatives in the study made a forecast for the HOV-2 lane, which is the current scenario west of I-495. The two closest alternatives that reflected the current I-66 scenario in the judgment of the research team were (1) full improvement to I-66, separate, reversible HOV-3 with access to I-495; and (2) full improvement to I-66, concurrent flow HOV-3. The second option appeared closest to reality, although it showed a 4-foot buffer between the HOV lane and the general purpose lane. That said, the mean absolute percent error was similar for the two alternatives: 21.2% (reversible HOV-3 alternative) and 22.3%

(concurrent flow HOV-3 alternative). Another complication was that hourly counts were not available in year 2010 for most of the study segments. Accordingly, the research team analyzed two days of hourly count data for year 2009 containing Quality 5 data as a surrogate for 2010 hourly count. The average of the days' A.M. peak hour volume was used to determine a K-factor for 2009 volume, and the K-factor for 2009 was then applied to the 2010 AADT volume to estimate the 2010 peak hour observed volume.

7. *The I-95 Clermont Avenue Interchange & Connector to Duke Street, Alexandria, Virginia Study* (Louis Berger & Associates, Inc., 1990) was based on a TDM forecast with a 1988 base year and a 2010 forecast year. The study included a no build alternative and five candidate build alternatives (CBAs), each of which included a full diamond interchange at I-95 and Clermont Avenue combined with one of five different connector alternatives to Duke Street. For example, CBA 1 is the construction of a new highway segment from the Eisenhower Avenue/Clermont Avenue intersection. The no build alternative reflected the future year network without the interchange and without the Eisenhower Avenue/Duke Street Connector. The research team determined that the Clermont Avenue interchange was present as of 2012 (Google Maps Street View, 2016), which reflects a build scenario, although it was not certain whether the interchange was constructed before 2010 as proposed in the study. However, the research team also confirmed that none of the five connectors to Duke Street under the five CBAs was actually built (VDOT GIS Integrator, 2015). Thus the actual scenario reflected neither a fully built alternative nor a no build alternative. Accordingly, the following approach was used to compare forecast and observed volumes. For interstate links, CBA 3 was used since the proposed interchange was built, the connector was not built, and Alternative 3 shows both the interchange and relative to the other CBAs the least amount of infrastructure for a connector. Because ramp volumes were not routinely collected until 2012 (Dunnavant, 2016b), the research team used 2012 AWT as a surrogate for 2010 volumes, and link ADTs were obtained from VDOT's Statewide Planning System (VDOT, 2015). For non-interstate links, the no build alternative forecast was used as no connector to Duke Street was actually built and the non-interstate observed AWT was obtained either from VDOT's TMS counter shapefile or from publications that contain traffic volumes for 2010 (VDOT, 2014). Finally, 24-hour intersection turning movements were given for a typical weekday, which had to be converted to link volumes. For example, the link between Edsall Road and South Pickett Road has the intersection of South Van Dorn/Edsall at one end and South Van Dorn/South Pickett at the other end. The link had two southbound forecast volumes: 32,000 (= 800 + 29,600 + 1,600) AWT for South Van Dorn/South Pickett intersection and 31,400 (= 21,500 + 2,800 + 7,100) AWT for the South Van Dorn/Edsall intersection. Accordingly, the two potential northbound volumes were 29,600 AWT and 27,800 AWT for South Van Dorn/South Pickett and South Van Dorn/Edsall intersection, respectively. Generally, the research team took the higher of the two volumes; thus 29,600 AWT was selected. Given a 32,000 AWT southbound volume, the two-way link volume was 61,600 AWT, which may be compared to the 2010 observed volume of 54,017 AWT.

8. *The Route 13 Corridor Study, Northampton County and Accomack County* (VDOT, 1988b), identified both short- and long-range improvements. Logically, one would expect capacity-driven improvements to have some effect on 2010 ADT—and if an improvement was not foreseen, this would affect the forecast. One example was the link between SCL Keller and

U.S. 13 Bus at Exmore, which had the highest error of 8,603. Although this section of Route 13 was changed from a two-lane undivided highway to a four-lane divided highway with turning lanes sometime between 1988 and 2010, the improvement was not noted in the study. The study suggested that the forecast was based on traffic trends for the past 20 years, but the research team was not able to use historical traffic information to replicate the given forecast.

9. *The Routes 17 and 360 Corridor Study: Town of Tappahannock* (VDOT, 1989b) assessed traffic flow in order to suggest future improvements through a section of road where Routes 17 and 360 merge in Tappahannock. As with several other studies, Equation 1 in the body of this report was used to align predicted and observed volumes. The study also showed a particularly large error (182%) for one segment where the Tappahannock Airport was located in 1988, and a contributing factor may have been the relocation of the airport. Without this segment, the mean percent error for the entire corridor decreased from 70% to 43%.

10. *The Route 40 Needs Assessment Study: Campbell County, Charlotte County, Lunenburg County, and Nottoway County* (VDOT, 1999a) was conducted to evaluate a 68-mile portion of Route 40 from Campbell to Nottoway County. In order to determine a 2014 interim forecast (given that the study had a 2020 forecast), linear interpolation between the 1996 ADT and 2020 forecast ADT was used. (See Study 37 for a detailed example of linear interpolation.) As with other studies, the accuracy of the forecast may have been affected by the extent to which anticipated improvements were built; however, only one forecast was provided (independent of the improvements made).

11. *The Routes 20/240 Corridor Study: Albemarle County* (VDOT, 1990a) forecast 2010 ADT for six segments on two roads using 1987 base year data. As with several other studies, the exact method used to develop the forecast was not given, and Equation 1 in the body of this report was used to align observed and forecast volumes. As with other studies, the accuracy of the forecast may have been affected by the extent to which anticipated improvements were built; however, only one forecast was provided (independent of the improvements made).

12. *The Route 608 Corridor Study: Augusta County, Fishersville, Stuarts Draft* (VDOT, 1996). To address anticipated development, this study determined appropriate transportation improvements throughout the subject corridor, which ranged from Route 254, north of Fishersville, to Route 656, south of Stuarts Draft. Three assumptions made by the research team are noted. The first assumption is that the study was similar to a TIA that uses trip generation rates, as the study stated: "Through data supplied by the Augusta County Department of Community Development, a forecast of land use for the year 2014 was developed along the corridor. Traffic volumes generated from this land use were added to the 1994 traffic volumes to represent future traffic volumes on the corridor." Given that the forecast traffic volumes were for the P.M. peak hour in a rural area in 1996, it appears unlikely that a TDM was used; at that time, TDMs were not used in rural areas. The second assumption is that of the two sets of forecasts noted in the study, the forecasts without roadway improvements (rather than those with roadway improvements) should be used for three reasons: (1) widening of the travel way and the shoulder was not performed (e.g., the recommended pavement width on Route 608 between Route 656 and Route 842 is 24 feet with 10-foot shoulders; however, VDOT's Road Inventory Management System database shows that the section of corridor has a pavement width of 18 feet with 2-foot shoulders

based on the last modified date of 2012 [Dunn, 2016]); (2) based on a review of the VDOT GIS Integrator, new facilities such as the relocation of Route 631 and Route 627 and a connector road from Route 608 to Route 909 were not built as of 2016 (in fact, the only visible improvements were reconstruction of Route 642, a connector road to Route 340, and the extension of Route 636); and (3) although the inclusion in the study of a drawing of an interchange at I-64 and Route 608 seemed to suggest an improvement to the interchange, an earlier 1995 map (VDOT, 1997) showed that the interchange already existed and the interchange did not seem to be improved since that time. A complication in determining that the forecasts without roadway improvements should be used is that detailed explanations for these improvements were not given in the study except in figures of proposed alignments and cross sections. The third assumption is that one link for which the volume was forecast should be excluded from the analysis because that link matches either of two different links and the research team was not sure which one to choose. Thus only 25 links were used in the evaluation.

13. *The Botetourt County Route 220 Study* (VDOT, 1999b) was conducted to determine the present and future transportation needs because of the impact of development along the Route 220 corridor in Botetourt County. Although the study used the elements of a TDM, it was classified as a TIA, based on the following statement in the study: "Traffic for the year 2015 was obtained using the TDM from the 2015 Roanoke Thoroughfare Plan in conjunction with the Institute of Transportation Engineers' (ITE) Trip Generation Manual. Projections were based on socio-economic data from the 2015 model year and on the trips generated from developments that are either proposed or under construction." The publication year is unclear: the study cover page shows a crossed-out "1999" with a handwritten "2000." The most recent observed volume recorded in VDOT's Traffic Monitoring System (TMS) at the time of analysis was 2014 (VDOT, undated a), which was used by the research team as a surrogate for 2015 observed volume. (One of the three links did not have an actual observed volume and the data type indicated "21-No Count, Invisible Mimic Link." The research team verified the volume of the link that was identical to the adjacent link.)

14. *The Capital Beltway Study (Capital Beltway Phase II: Short Term and Mid-Term Recommendations Report)* (JHK & Associates et al., 1989) listed three future scenarios: Scenario A, no change to the beltway but the construction of four new facilities and 45 network improvements; Scenario B, no change in transportation infrastructure; and Scenario C, widening the beltway to six lanes in each direction. Although Scenario C can be eliminated as the beltway is not six lanes in each direction, the research team was not certain as to whether the future scenario that most closely matched reality in 2010 was Scenario A or Scenario B. The reason for this uncertainty was that some, but not all, of the network improvements associated with Scenario A were built. Four new facilities in Scenario A appear to have been built: (1) the Fairfax County Parkway; (2) the Dulles Greenway, which was listed in the study as "Dulles Toll Road Extension"; (3) the "Clermont Interchange," which is presumed to have been built based on a review of Froehlig and Roberson (2014), which noted that a "Clermont Dr underpass" was eliminated when the Eisenhower Avenue interchange was built; and (4) the "Indian Head Hwy/I-295 Interchange," which is presumed to have been built based on a review of Anderson (undated), which noted that in 1990, I-295 was connected to Route 210 (which is Indian Head Highway). However, whether the 45

network improvements were built is not clear. A detailed review of 10 of the 45 segments showed that 5 segments were widened to four or six lanes and the other 5 were not (based on the use of the Statewide Planning System (VDOT, 2015) and Google Maps Street View in 2015) (see Table B1). Because 5 of the 10 proposed improvements examined by the research team were made and because all four new facilities were built by 2010, the research team chose Scenario A to represent the future scenario that most closely represented year 2010, comparing the 2010 forecasts from Scenario A with the observed 2010 ADT volume.

Table B1. Comparison of Planned and Actual Improvements Associated With Scenario A in the Capital Beltway Study

Road	From	To	Improvements Forecast for 2010 (Both Directions)	Observed Facility Built as of 2010 (SPS & Google Maps Street View)
Route 1	Route 233	15th St.	Widen to 6 Lanes	Built
Route 1	Occoquan River	Route 623	Widen to 6 Lanes	4 lanes (not built)
Route 7	DATR	Fairfax Co. Line	Widen to 6 Lanes	4 or 5 lanes (not built)
Route 7	Falls Church	I-495	Widen to 6 Lanes	4 lanes (not built)
Route 7	Columbia Pike	7 Corners	Widen to 6 Lanes	5 lanes (not built)
Route 7	Loudoun Co.		Widen to 6 Lanes	Built
Route 29	Graham Rd.	Fairfax Co. Line	Widen to 4 Lanes	Built
Route 28	I-66	Route 7	Widen to 6 Lanes	Built
Route 123	Occoquan	Fairfax Co. Parkway	Widen to 4 Lanes	Built
Route 236	I-395	I-495	Widen to 6 Lanes	4 lanes (not built)

Source: JHK & Associates et al., 1989.
SPS = Statewide Planning System; DATR = Dulles Access Toll Road.

15. *The Route 221/460 Corridor Study, Roanoke and Botetourt Counties* (VDOT, 2002), focused on determining needs for a 7.59-mile corridor. The study forecast the 2020 volume using a TDM for the 2020 Roanoke Thoroughfare Plan. These projections were "supplemented" with projections derived from a historical trend line analysis—which indicated that the projection method used in the study was based on both a TDM and a trend line analysis. Although both were used, the research team judged the TDM to be the dominant forecast method because of the use of the word "supplemented" in the study. To accommodate the projected increase in volume, improvements were recommended such as widening Route 221/460 from four to six lanes (with bike facilities) and removing crossovers. VDOT's Road Inventory Management System database showed that as of 2015, none of the sections in the corridor had been widened from four to six lanes. Accordingly, the 2020 no-build forecast volume was used. To obtain an interim 2015 forecast, linear interpolation based on 2000 and 2020 volumes was used. (See Study 37 for a detailed example of linear interpolation.)

16. *The Route 360 Corridor Study: Town of Warsaw* (VDOT, 1993) recommended improvements to address expected increased traffic (by 2010) on Route 360 and Route 3. Although the study also mentioned "anticipated development," the forecast ADT was based on historical traffic growth in Warsaw, and consequently the research team judged this to be a trend analysis. Equation 1 in the body of this report was used to align observed and forecast volumes. Because the study recommended a relocation of Route 3, the fact that

Route 3 has been relocated suggests that the forecast assumed future conditions that ultimately transpired.

17. *The Dulles Toll Road Extension Route 267 Draft Environmental Document* (VDOT, undated b). This study was performed to forecast traffic volumes on a proposed extension of the Dulles Toll Road—a facility that would later become the Dulles Greenway—that would extend from Route 28 (Sully Road) to the Route 7/15 Bypass near Leesburg. (The study did not show a publication date; however, it appears to use 1986 traffic data as being the most recent and indicated public meetings held in 1987. Therefore the publication year was no earlier than 1987 but could have been later.) Examination of the Draft Environmental Impact Statement showed three assumptions that would logically govern forecast accuracy. First, the alignments of the study were not firmly established: the Draft Environmental Impact Statement noted three alignments that were similar in length (13.6 miles, 14.1 miles, and 14.8 miles). The number of interchanges was similar but not identical: two of the alignments had eight interchanges (Routes 7/15, 654, 653, and 659; West Spine Road (thought by the research team to be represented now by Claiborne Parkway); East Spine Road (now Ashburn Village Road); Routes 645/607; and Route 606), and the third alignment included a ninth interchange with the "proposed Washington Bypass"; maps and language elsewhere in the document (VDOT, undated b) indicate that this interchange would be in roughly the middle portion of the corridor and located half a mile west of a tributary to the Potomac River (Goose Creek). Second, the study did not discuss tolls, but tolls would influence demand to some degree. Third, the details of how planned improvements (noted in the study) were ultimately implemented, such as the proposed widening the Dulles Toll Road from four to six lanes between Routes 28 and Route 7, the proposed upgrading of intersections on Route 7 to interchanges, and building the proposed "spine roads" through subdivisions, would have affected traffic volumes. The research team also observed that some of the road names have changed since the study was conducted: although most road names in the study could be verified with the VDOT GIS Integrator, other data sources were required in order to determine the locations of where Route 267 was crossed by Route 654 (Geoview.info, 2013), East Spine Road (Loudoun County Department of Planning, 2003), and West Spine Road (Letourneau, 2014) along with visual inspection.

18. *The Route 240 Corridor Study: Albemarle County* (VDOT, 1990c) was conducted to identify the major problem areas along Route 240. The study did not mention the method used to develop forecasts for 2010. The study forecast ADT for only two segments of Route 240. Several recommendations were made such as reconstruction of the facility, and such improvements could affect future traffic volumes. However, the impact of making (or not making) such improvements on forecasts was not noted.

19. *The Pulaski Area—Year 2000 Improvement Plan* (VDH&T, 1981) forecast 2000 ADT using a regional model in the town of Pulaski with 1980 base year data. Two projections were generated, one for a "build" scenario and another for a "no build" scenario. Although some improvements were relatively minor (e.g., the removal of parking), 23 of the proposed improvements comprised significant capacity expansions. For example, 1 improvement was to construct a 52-foot roadway (curb to curb) between the northern corporate limits of Pulaski County and Route 648. In this particular case, since the road was only two lanes

(one lane in each direction, with a width of 24 feet or less), it was clear that the improvement was not made. Of the 23 capacity improvements recommended in the plan, 18 were not built and 5 were present as of 2004, meaning that 5 improvements at most were made before 2000. Further, the most significant network improvement proposed by the study was the unbuilt Route 11 Bypass. Finally, the only improvements made appeared to be the addition of gutters and curbs and the removal of curbside parking areas (Google Earth, 2015). Even these improvements were not fully made; for instance, curbside parking was not eliminated. Therefore the case of the no build scenario was used for forecast values. A more recent study was conducted with a base year of 2000 in Pulaski, predicting volumes for year 2020. That study entailed collecting additional traffic data rather than using VDOT traffic counts. However, comparison of the volumes from that study with the VDOT traffic counts showed a mean absolute difference of about 18%.

20. *The Route 29 Corridor Study: City of Charlottesville and Albemarle County* (U.S. Department of Transportation et al., 1990) used an urban travel demand forecasting model to project traffic volumes for 2010 on various links affecting Route 29 within the city of Charlottesville and Albemarle County. The study showed eight alternatives for improving transportation along with the no-build scenario, and each of the alternatives had a different forecast volume. For example, Alternative 6-7A showed an eastern bypass; Alternative 9 showed an expressway; Alternatives 10, 11, and 12 each showed a western bypass; and the no-build scenario indicated that a portion of Route 29 had been widened to three lanes in each direction (between the Route 250 Bypass and the South Fork Rivanna River) without any bypass being built. Since the bypass had not been constructed as of 2010, forecasts associated with the no-build alternative were used, although there might have been other assumptions implicit in making the 2010 forecasts that were not provided in the study. In 1990 when the study was published, VDOT was using the MINUTP travel demand software, and the modeling files provided to the research team (Guiher, 2015) were in that format. In some cases, a link for which a forecast volume was available (from the study) did not line up perfectly with a link for which an observed volume was available. For instance, one link had a length of 0.05 miles (in the study) whereas the link with an observed volume had a length of 0.70 miles (based on a review of Google Maps in 2014). Further, there were several links where the endpoints could not be determined. Accordingly, although the study provided 64 links where a forecast was made, only 17 links were used in this report, where the forecast and observed volumes were compared. For these 17 links, 6 had a higher-than-predicted volume and 11 had a lower-than-predicted volume. The average absolute percent error was about 58%, but if one removes the 2 links with the highest errors, the average percent error improves to 23%.

21. *The Peninsula Area Transportation Study, Recommended Transportation Plan, Vol. II* (Deleuw, Cather & Associates, 1967) forecast AWT for the year 1985 with a base year of 1967. Although the study was conducted in 1967, Volume I of the study (Wilbur Smith and Associates, 1965) showed components such as trip distribution, which suggests the study was based on a TDM forecast. In order to identify the start and end node, route number, and street name for each of the forecast links, the study area road map was georeferenced using a 2015 VDOT road network layer in ArcGIS. (As with Study 1, a link is a section of road between two specified end points.) Although this study forecast AWT, 1985 AWT volumes

were not available. As a result, Table 3 in the body of this report compares forecast AWT to the observed ADT for this study. In cases where the 1985 observed counts were not recorded for a link, the average of the 1984 and 1986 observed volumes counts was applied. Further, because secondary and urban system (e.g., city) counts were not maintained by VDOT at that time, such volumes were acquired separately from VDOT staff who had access to 1986, 1987, and 1988 traffic volumes (which were thus a surrogate for year 1985 volumes).

22. *The Hampton Roads TDM Study* (*2000 Hampton Roads Model Users Guide*, Michael Baker Jr., Inc., 2004). The Cube model application for the Hampton Roads TDM Study is compatible with ArcGIS such that one can compare forecast volumes (from the model) to observed volumes (provided by Lee [2014] as a shape file format for counters of VDOT's TMS database where the shape file contains latitude and longitude geospatial information for each counter). When the regional model is exported into ArcGIS, the links are split by direction for each roadway such that a forecast represents a directional volume. In Cube it is represented as V_1. Cube also offers a value of VT_1 to represent the "final assignment total two-way volume" (Lee, 2015). All interstates and one-way roads were evaluated using the V_1 directional volume. All other links were evaluated using the VT_1 two-way volume. There were some cases where traffic was not forecast on a roadway in either the base year or the forecast year. These links were discarded from the data set. The model does not forecast volumes for Accomack County or Northampton County but does represent 10 other localities within the Hampton Roads District: City of Chesapeake, City of Norfolk, City of Portsmouth, City of Suffolk, City of Virginia Beach, Isle of Wight County, City of Newport News, City of Hampton, City of Williamsburg, and York County. After the study had progressed, it was not clear from the available documentation if the model had provided forecasts for ADT or AWT. Regarding the base year calibration, the model documentation indicated that "traffic count data for 2000" were used in the validation effort and provided screen lines for observed and estimated base year volumes. Because two of those screen lines entailed just a few links, the research team initially thought it would be possible to tabulate the year 2000 observed volumes in the model documentation; compare them to observed ADT and AWT reported by VDOT (2001); and from that comparison determine whether the base year calibration had been with ADT or AWT. (If the screen line counts from year 2000 had matched observed ADT from 2000, the research team would have thought that the forecasts from the model for year 2011 were also for ADT. If the screen line counts from year 2000 had matched observed AWT from 2000, the research team would have thought that the forecasts from the model for year 2011 were also for AWT.) However, one observed screen line volume from 2000 according to the model documentation was 174,959, which is the sum of volumes for the James River Bridge (U.S. 17), the Hampton Roads Bridge Tunnel (I-64), and the Monitor-Merrimac Memorial Bridge-Tunnel (I-664). This "observed screen line volume" differed from the observed volumes for year 2000 (VDOT, 2001), which were 167,000 for ADT and 170,000 for AWT. For the Coleman Bridge screen line, whereas the reported volume was 31,134, the ADT and AWT were 27,000 and 28,000, respectively (VDOT, 2001). A follow-up communication with staff of the Hampton Roads Transportation Planning Organization (Dale Stith, personal communication, April 4, 2016) suggested that for this older model, it was probably the case that the forecast was for AWT. Accordingly, the performance metrics reported in Table 3 in the body of this report are based on comparing the model forecasts to observed AWT. Table B2 shows how the performance

changes if it turns out that, contrary to the research team's understanding, the forecast was for ADT instead of AWT: the mean and median absolute errors would each have changed by 2 percentage points.

Table B2. Performance of Forecasts for Study 22

Compare Forecast From Study 22 to Observed	Mean Error	Mean Absolute Error	Mean Percent Error	Mean Absolute Percent Error	Median Error	Median Absolute Error	Median Percent Error	Median Absolute Percent Error
ADT	1,957	4,776	21%	49%	1,579	3,610	11%	33%
AWT	1,036	4,689	14%	47%	570	3,136	4%	35%

ADT = Average Daily Traffic; AWT = Average Weekday Traffic

23. *The 2010 Statewide Highway Plan, Culpeper District* (VDOT, 1989c). The purpose of this study was to provide a document that identified highway needs for Virginia's administrative systems and between construction districts and local jurisdictions. An analysis was conducted of the adequacy of the rural and urban highway system to handle forecast year 2010 traffic volumes. Where deficiencies were identified, a recommendation was made that would provide an acceptable LOS for the forecast year. The study forecast ADT for Albemarle County, Culpeper (county and town), Fauquier County, Fluvanna County, Greene County, Louisa County, Madison County, Orange County, Rappahannock County, City of Charlottesville, and the Town of Warrenton.

24a. *The Statewide Highway Plan: Thomas Jefferson Planning District* (VDH&T, 1984a) has 79 links with a base year of 1981 and a forecast year of 2005. The highway needs with forecasts were listed by jurisdiction (Albemarle County, Fluvanna County, Greene County, Louisa County, Nelson County and City of Charlottesville) and by system (Interstate, primary, secondary, and urban). Traffic volumes from just two jurisdictions (Albemarle County and Fluvanna County) were used for the evaluation (67 links from Albemarle County and 12 links from Fluvanna County). To align forecast and observed volumes, Equation 1 in the body of this report was used.

24b. *The Statewide Highway Plan: Richmond Regional Planning District* (VDH&T, 1984b) forecast 2005 ADT by jurisdiction (City of Richmond and counties of Charles City, Chesterfield, Goochland, Hanover, Henrico, New Kent, Powhatan, and Ashland) and by system (interstate, primary, secondary, and urban). Three jurisdictions were used for the evaluation: Charles City County, Chesterfield County, and Goochland County, for a total of 86 links. In order to match the study-reported link with the database link, the research team performed the following steps. First, Google Maps was used to locate the jurisdiction and route name with the start and end termini. Second, using ArcGIS software and an OpenStreetMap basemap, the particular route was identified. (With GIS, a shape file that is compatible with VDOT's TMS database containing 2005 observed volumes can be used.) As with other studies, Equation 1 in the body of this report was used.

24c. *The Statewide Highway Plan: 5th Planning District* (VDH&T, 1984c) has a base year of 1981 and a forecast year of 2005. Initially, 286 links were recorded; however, only 144 links had a corresponding observed volume. The study included four rural counties:

Alleghany, Botetourt, Craig, and Roanoke. The reason most of the links were major collector roads is that all four counties were rural. The links were evaluated for their forecast accuracy for ADT and DHV, which the research team treated as a peak hour volume. To generate the peak hour volume, the ADT was multiplied by the K-factor.

25. *The Statewide Highway Planning System (SHiPS) (a VDOT database).* The research team ultimately obtained 2,493 links whose forecasts as recorded in SHiPS could be evaluated. Within the SHiPS database, there were two tables of interest from which data were extracted on April 6, 2015: SHiPS_TBL_EXISTING_ROADS_FORECASTS and SHiPS_TBL_PLANNING_DATA. Although there were 41,300 forecasts, ultimately only 2,493 links were selected, based on the application of four sequential criteria. First, the horizon year and forecast year must refer to 1994 and 2015, respectively. Links with errors (e.g., where the forecast year was the same year or earlier than the active date) and links with other values (e.g., a forecast for some year later than 2015) were excluded, which reduced the data set to 6,894 links. Second, any links with an "inactive date" were removed. For example, a particular segment (Route 1503) showed for the 2015 forecast an active date of December 31, 1994, yet an inactive date of March 11, 2007. When segments with an inactive date were eliminated, this reduced the data set further to 5,641 segments. Third, the start and end nodes for each link matched those in VDOT's TMS database. In some cases, although the table SHiPS_TBL_PLANNING_DATA showed a single link with a given start and ending milepost, the corresponding data in the TMS database showed that a given section may represent multiple links. For example, as shown in Table B2, for the link with JRSTAGID 0530625080, the start and end mileposts in SHiPS_TBL_PLANNING_DATA (11.43 to 12.29) actually referred to three different segments in the TMS database. Accordingly, such links were excluded from the analysis. (Had this step not been followed, the link in Table B3 with a 2015 forecast of 18,000 and a volume of 45 would have had an error of 40,000%.) This step yielded 2,494 links. Fourth, all links must have a volume greater than 0. One link had no volume, so exclusion of this segment reduced the data set to 2,493 links. This final data set of 2,493 links consisted of 867 urban arterial links; 1,496 rural two-lane links; 36 freeway/expressway links; and 94 rural multi-lane links. The evaluation compared forecast volumes for year 2015 with observed volumes for 2013. It was assumed that these forecasts were for ADT, as the documentation did not state ADT versus AWT.

Table B3. Information for Highway Segment With JRSTAGID 053-0625-080

Source	JRSTAGID	Link ID	Start MP	End MP	Start Node	End Node	2015 Forecast	2013 Volume
1	0530625080	--	--	--	--	--	18,000	--
2	0530625080	--	11.43	12.29	428113	428011	--	45
3	--	301483	11.43	11.7	428113	428117		9,850
		301484	11.7	12.03	428117	429496		45
		301485	12.03	12.29	429496	428011		9,630
4	0530625080	--	11.43	11.7	428113	428117	18,000	--

Sources: 1 = Statewide Highway Planning System Table SHiPS_TBL_EXISTING_ROAD_FORECAST; 2 = Statewide Highway Planning System Table SHiPS_TBL_PLANNING_DATA; 3 = information extracted from VDOT's TMS database (VDOT, undated); 4 = Statewide Highway Planning System.
MP = milepost.

26. *The University of Virginia Research Park Study* (Cox Company, 2008). There were six assumptions made by the researcher team that influenced the evaluation of this study. First, the evaluation focused on background traffic only. The study forecast A.M. and P.M. peak hour traffic for year 2015 at several intersections in the vicinity of the University of Virginia Research Park in Albemarle County. The study developed two sets of forecasts at the park: 3.0 million and 3.7 million square feet, which represented a large amount of growth relative to the 434,500 square feet that had been developed as of June 2006. Both forecasts presumed the construction of two major roadway improvements: (1) an extension of Lewis & Clark Drive to Innovation Drive, and (2) the construction of Meeting Street from North Hollymead Drive to the intersection of Airport Road and Innovation Drive. As of 2015, however, neither transportation improvement had transpired; further, the amount of developed land was only 554,000 square feet (University of Virginia Foundation, 2015; Wilson, 2015). Thus to evaluate the accuracy of the study, the research team examined the forecast of background peak hour traffic. Second, although 2015 was the forecast year, the research team used 2014 traffic counts (VDOT, 2015a), as 2015 observed counts were not available in the database. Third, the research team had to convert intersection counts to link counts, as the observed data were link counts. For example, for the intersection of Airport Road that runs east-west and Route 29 that runs north-south, for the evening peak hour, the forecast data included three turning movements that entered the intersection: 2,071 northbound vehicles (on Route 29), 230 eastbound right-turning vehicles (on Airport Road), and 274 westbound left-turning vehicles (on Airport Road). Accordingly, the forecast of the northbound evening peak hour volume on Route 29 was 2,575 (2,071 + 230 + 274). The southbound evening peak hour volume of 2,349 (129 + 2031 + 189) was added to this volume. The total peak hour volume of Route 29 North-South was 4,924, whereas the observed link volume was 3,811. Although the forecast was made for the morning and evening peak hour traffic volumes, the observed data gave only a single peak hour volume. This single peak hour observed volume was thus compared to the larger of the morning or evening forecast peak hour volume for each link. Fourth, the observed peak hour volume was determined by multiplying the K-factor with the corresponding ADT (Transportation Research Board, 2000). However, for some observed volumes, a K-factor was not given; hence, the average K-factor of the remaining segments was used. In the cases when the link comprised different volumes and hence different K-factors, a weighted average K-factor was used. For example, Route 649 had two K-factors: 0.094 (for 0.46 miles) and 0.096 (for 0.31 miles). Therefore, the weighted K-factor was 0.095 ((0.096 * 0.46 + 0.094 * 0.31) / (0.46 + 0.31)). Fifth, for some links, more than one intersection could govern the forecast link volume. For example, for the observed link volume for the section of Route 29 between Airport Road and Camelot Drive, three different link volumes could be obtained as follows: (1) sum the appropriate turning movements north of the Route 29/Airport Road intersection, (2) sum the appropriate turning movements south of the Route 29/Lewis & Clark Drive Intersection, and (3) sum the appropriate turning movements north of the Route 29/Lewis & Clark Drive intersection. In this study, the highest of the three options was chosen, given that the lower intersection volumes would, in the research team's opinion, have reflected traffic being absorbed by driveways that potentially would be included in a traffic count. Had the research team used the lower rather than the higher volumes, when absolute values were used, the average link error would decrease from 383 to 293 vehicles per hour and the average percent error would decrease from 35% to 28%. Sixth, although this was a land development study, the research team

categorized it as a trend analysis study because (1) the development proposed in the study was not built, and (2) only the background traffic forecast was used in the analysis and that growth in background traffic was based on a trend analysis.

27. *The Rivanna Village at Glenmore TIA Study* (Cox Company, 2001) is a land development forecast where the subject of the study (Rivanna Village) was not built. However, the analysis identified two adjacent sites where future development, along with growth in existing traffic, would result in background traffic. Thus the study was evaluated as a partial land development study based on these adjacent sites. The study sought to provide information for a "worst case" situation—that is, the maximum amount of travel demand that could be generated by background traffic at these two adjacent sites. (For example, based on existing development as of 2001, field observations showed the observed daily trip generation rate to be 6.766 trips per dwelling unit, whereas national literature cited in the study suggested a rate of 9.43; the study used the higher rate). In 2001, the study used two approaches for estimating 2006 traffic volumes at five intersections: Route 250/Route 22, Route 250/North Milton Road, Route 250/Moose Lane, Route 250/Glenmore Way, and Glenmore Way/Steamer Lane. One approach was to use multipliers based on historical traffic projections. For traffic on Route 250 a linear increase of 3% per year (e.g., a multiplier of 1.15) and for traffic on Route 22 a linear increase of 2.1% per year (e.g., a multiplier of 1.105) were applied to the 2001 counts. Between the two reported projections for 2006, Appendix A from the study was used, as the research team could replicate those projections. For turn movements on Glenmore Way and Steamer Lane, however, 2006 projections were based on expected land development at the two adjacent sites. Thus a complication arose because the sites were partially built. In 2001, the current number of units in Glenmore was 475, and it was expected that by 2006, a total of 800 units would exist. It was also expected that an additional 26 duplexes would be built at an adjacent parcel. However, the Residential Development Index had shown that there was a total of only 650 detached dwelling units in Glenmore as of December 2006 (Nelson, 2015), and a review of available site plans in 2015 (Albemarle County, Virginia, 2015) showed that the 26 duplex units had not been built. Accordingly, the background traffic for 2006 was scaled to reflect these lower amounts of development (i.e., 650 rather than 800 Glenmore units and 0 rather than 26 duplexes). Thus rather than generating 3,273 daily trips from 325 new Glenmore Units plus 26 new Bieker duplexes, the forecast was modified to reflect that only 1,651 trips would be generated from 175 Glenmore units and 0 new Bieker duplexes—hence only 50.4% of new Glenmore and Bieker trips should be included for the 2006 forecast year. As an example, total peak hour volume (in both directions) on Glenmore Way was forecast in 2006 to be 580 vehicles (based on three separate turning movements). Part of this volume was the 2001 peak hour volume (267 vehicles), and part was that generated by the new Glenmore and Bieker units (313 vehicles). Since only a portion of the expected Glenmore and Bieker development was built in 2006, the 313 vehicles were cut to 50.4% of their original number (158 trips), and thus had land development in 2006 proceeded in a manner similar to that expected in 2001, Glenmore Way would have had a two-way ADT of 425 trips. For 2011, an exact estimate of the number of units in Glenmore that had been built was not available; however, Albemarle County staff, after performing additional database queries, noted that a rough estimate of the number of units in Glenmore as of 2011 was 687 (Roderick Burton, personal communication, November 20, 2015). Accordingly, the 2011 background

traffic was scaled in a manner similar to that described previously to reflect the fact that there were 687 (not 800) Glenmore units and 0 (not 26) duplex units. Forecast peak hour volumes for 2006 and 2011 were thus derived for four segments: Route 22, Route 250, Glenmore Way, and North Milton Road. These forecast peak hour volumes were then compared to observed peak hour volumes published by VDOT (2007a, 2012).

28. *Stonefield at Route 29* (Strohhacker, 2010) generated forecasts on at least seven occasions: 2001, 2002, 2005, 2009 (June), 2009 (December), 2010, and 2011. Among these seven forecasts, differences were noted in (1) the expected amount of development that would occur at the site, (2) the background traffic to which the site's traffic would be added, (3) the time period of interest, (4) the roadway section of greatest interest, and (5) the amount of information in the forecast. The focus of the studies also differed. For example, the 2010 study addressed whether an access management exception should be granted on Hydraulic Road and thus did not focus on Route 29 traffic. By contrast, the 2011 study examined whether a multi-way stop-controlled intersection should be installed internal to the site. Collectively, the seven studies suggested that in some cases a land development study will not have a single forecast but rather multiple forecasts that change as economic and traffic conditions evolve. For the purposes of this retrospective evaluation, the PM peak volumes generated in 2010 were chosen as the forecast because the link volumes could be understood best. These forecasts (for year 2012) were compared to the observed 2012 volume data. In order to compare 2012 observed volumes to 2012 forecast volumes, the research team had to acknowledge five details that render such a comparison imperfect. First, the forecast and observed segments do not align perfectly: the study examined Hydraulic Road between Route 29 and Commonwealth Drive (a 0.42-mile section), but there was one observed volume between Route 29 and Solomon Road (a 0.39-mile section that fits within the section). Second, as noted for several other studies, the link for which a volume is forecast is only a portion of the link for which an observed volume exists. For example, Hydraulic Road, Solomon Road, and Commonwealth Drive are sufficiently close (0.03 miles) that they can be treated as the same point. Although there is only one observed volume for that section, the study showed three forecasts for this section: Route 29 to Swanson Drive, Swanson Drive to Cedar Hill, and then Cedar Hill to Commonwealth Drive. Accordingly, a weighted average of these forecasts was used as per Equation 1 in the body of this report. Third, because the study provides turning movements rather than link volumes, these turning movements must be aggregated to develop a link volume. Fourth, some traffic volumes are lost between intersections as vehicles turn in and out of the development such that different volumes are obtained depending on how intersection counts are aggregated; the research team chose the lower volumes under the assumption that when VDOT placed tube counters, VDOT would have placed them in a location where traffic immediately entering or exiting the site would not have been captured. (Because the forecast volume was higher than the observed volume, this assumption did not increase the reported error.) Fifth, as discussed previously, this evaluation used the 2010 forecasts made for year 2012; however, other forecasts, such as those made in 2001, could have been evaluated.

29. *The Town of Orange 2020 Transportation Plan Technical Report* (Michael Baker Jr., Inc., 2002) identified existing and future transportation needs for the town of Orange and recommended transportation improvements. The base year was 2000 and the forecast year

was 2020 with an interim year of 2010. Recommendations for year 2010 included reconstructing Spicers Mill Road to make it a two-lane urban roadway, extending Byrd Street north to connect with Montebello Road, and widening Byrd Street. The forecast was trend-based: the study stated that "the primary source of information in determining the traffic growth rates is the set of historic counts." To evaluate the forecasts, only 2010 ADT was compared to 2010 observed ADT from VDOT's TMS database (VDOT, undated a).

30. *The Route 360 Corridor Study: Hanover County, From Chickahominy River Bridge (Henrico County) to Pamunkey River Bridge (King William County)* (VDOT, 1990d). The specific method for generating the forecasts in this study was not given; however, the traffic forecasts appeared to reflect what would happen if no improvements were made. For example, the corridor study was divided into five sections, with each section having forecasts (in an analysis section) and then improvements for how to accommodate the traffic (in a recommendations section). (This may have been a logical approach to the extent that there were not alternative routes in the immediate area.) Forecasts were made in 1990 for year 1995 (in some cases) and for year 2005 (in all cases), and thus only 2005 forecasts were evaluated. It was noted that for one segment the study indicated "[e]xisting average daily traffic on this segment ranges from 29,250 vpd at the Chickahominy Bridge to 27,650 vpd at the west ramp of I-295," whereas for the 2005 forecast, the study referred to the segment as a single segment. However, observed traffic counts subdivided this roadway into four segments; accordingly, a weighted average based on those four segments was used. The research team could not determine the location of seven segments of road based on the information given in the study. Thus the study contained a total of 19 segments with both observed and forecast volumes for year 2005. Although the mean and median absolute percent errors were 64% and 59%, respectively, for all 19 segments, the mean and median errors were lower for the primary segments only with values of 39% and 32%, respectively.

31. *The Route 10 in Chesterfield County Study* (Johnson, 2001) covered four traffic segments and provided two forecasts: one for ADT and one for peak hour volume, each for the two forecast years of 2006 and 2014. For ADT, the mean percent error grew from 26% (for the 2006 forecast year, i.e., a 5-year horizon) to 40% for the 2014 forecast year (i.e., a 13-year horizon). One unusual aspect, however, was that based on a comparison of forecast data and observed data (VDOT, 2007b, 2015c), the four segments showed a high K-factor in each of the forecast years of approximately 0.15. For example, the K-factor for the forecast year in 2014 for Route 10 from Route 746 Enon Church Road to Route 827 was 0.15, whereas the observed value in 2001 when the study was conducted was 0.088 and the observed value in 2014 was 0.089. For the peak hour only, the four segments showed similar mean average percent errors for 2006 and 2014 of 90% and 96%, respectively, for an overall mean error of 93%. Had an average K-factor for 2006 and 2014 been used (of about 0.1045) rather than the value of 0.15, the average percent errors for 2006 and 2014 would have been 32% and 36%, respectively, for the DHVs (assuming those are peak hour volumes). In short, the reason the DHV percent error was considerably larger than the ADT percent error was the large K-factor that was presumed to exist during the forecast year.

32. *The Watkins Centre Traffic Impact Study* (Volkert & Associates Inc., 2007) has a base year of 2005 and a forecast year of 2024. Since the study did not include an interim year forecast

and because the base year was relatively close to the observed year, the research team did not assess the study's forecast accuracy and it is not listed in Table 3 in the body of this report. The study used a four-step TDM, a traffic analysis based on ITE guidelines, and Synchro7 traffic simulation software and made predictions for P.M. weekday peak hour volumes.

33. *The Trip Generation and Distribution Study, West Creek Parkway, Goochland County, Virginia* (Frank Coleman & Associates, 1988) focused on one phase of the West Creek development, with particular emphasis on West Creek Parkway, and forecast ADT traffic for 2007 with a base year of 1997. Although the study mentioned that the 2007 ADT and DHV for "Alternate 4 modified" were used as background traffic, no clear indication was given for the meaning of "Alternative 4 modified." The study explicitly referred to the fourth edition of the *ITE Trip Generation Manual.* It appeared to the research team that all developments in the expected scenario except the Ridgefield Parkway extension had been built as of 2015. Accordingly, 2007 forecast volumes were used except for Ridgefield Parkway, which was excluded from the evaluation. In some instances where observed and forecast volumes did not align, it was not possible to use Equation 1 in the body of this report because the link length was not available in the study. In those cases, a simple average was used. For example, the 2007 observed volume of a 1.84-mile length of Route 6 from Route 621 (Manakin Road) to Route 288 was 11,000 ADT. The two forecast links that corresponded to this observed link had volumes of 6,854 and 8,991; the average of these was thus the observed volume.

34. *The Route 1 Appomattox River Bridge and Approaches Location Study: Petersburg to Colonial Heights* (Hayes, Seay, Mattern & Mattern, 1989) evaluated a range of alternatives for the replacement of the Appomattox River Bridge along with the widening and realignment of the approach roadways. Although the study discussed 10 alternative scenarios (i.e., lane widening, turning lane, and rebuild of bridge including a no build scenario), the travel volumes and patterns were assumed by the research team to be similar for all alternatives based on the available forecast travel data. The volume was forecast based on 20-year travel demand, which includes the four-step travel demand process. A complication was that the study appeared to give volumes for the entire corridor and the team was not always certain they could align individual forecast link volumes with individual observed link volumes. Accordingly, nine links from the study were evaluated for forecast accuracy.

35. *The Route 1 Corridor Study: Fairfax and Prince William Counties* (TransCore et al., 1997) identified current and future transportation needs from the Prince William/Stafford County Line to the Fairfax County/Alexandria City Line in year 2020. Although the exact forecast method used was not provided in the study, it appeared that the forecasts were based on a TDM, as the study stated: "The travel demand forecasting model developed for the Route 1 Corridor Study was based on the MWCOG regional model and had additional zone and network detail in the corridor." The study anticipated several improvements would be made: widening Route 1 in the vicinity of the Telegraph Road, Pohick Road, and Lorton Road intersections; adding left-turn lanes at Woodlawn Road and Buckman Road in Fairfax County; improving the vertical alignment of Route 1 between Canal Road and Stage Coach Road; raising and widening the Neabsco Creek Bridge; and widening the southbound lanes

of Route 1 on Main Street in Dumfries in Prince William County. The study also indicated that all other projects listed in the Constrained Long Range Plan were assumed to be built by 2020 under this baseline scenario. With the help of Google Maps and the Statewide Planning System (VDOT, 2015), it appears that the proposed improvements listed in the study existed by 2015. Given the 2020 forecast year, a linear interpolation was used with the observed 1995 ADT and the forecast 2020 ADT to obtain a 2014 forecast that could be compared to a 2014 observed value. For example, Segment 1 had 11,000 ADT in 1995, a forecast of 46,000 ADT for 2020, and thus assuming linear growth, the segment would add 1,400 ADT annually during that 25-year period. Accordingly, for the 19-year period from 1995-2014, one would expect the segment to add 19 * 1,400 ADT to the 11,000 ADT in 1995 for a 2014 interim forecast of 37,600 ADT.

36. *The Richmond International Airport Corridor Feasibility Study* (LPA Group and David Volkert & Associates, 1999) proposed four alternative scenarios along with a modified base condition. All four model alternatives showed a connector to the airport (between Route 895 and I-64) being built with additional improvements to I-64. For example, Alternative 1 widened I-64 and southbound Airport Drive and provided a two-lane directional ramp between the two. Alternative 2 was the same as Alternative 1 except it also provided a dedicated ramp for airport access. Alternative 3 is similar to Alternative 1 except it provides an additional exit ramp from I-64 EB but the ramp is located west of the I-64 interchange. Alternative 4 is fundamentally different from the first three alternatives as it provides two directional ramps: one for access to the airport from I-64 EB and one for access to I-64 WB from the airport. In the modified base condition neither the Airport Connector nor the changes in I-64 interchange are made. However, in practice, only the airport connector was built (thus the modified base condition cannot be used) and none of the I-64 improvements was made (thus Alternatives 1, 2, 3, and 4 cannot be used). The only visible change made since the study was the connector to I-895 (verified by the VDOT GIS Integrator and an aerial image from Google Maps, 2015), which made Alternative 3 the closest alternative in the opinion of the research team. Although the study forecast traffic for 2015, the model outputs were compared to the 2014 traffic counts of VDOT.

37. *Old Keene Mill Road and Rolling Road Intersection Study: Fairfax County* (Azimi, 2015a, b, c). Although forecasts based on the Fratar method exist, the research team could not find cases where a forecast had been made and the forecast year had elapsed. Accordingly, the research team obtained turning movement data from a single intersection where turns were collected 7 years apart: in 2005 and 2012. The data are for the intersection of Old Keene Mill Road (Route 644) and Rolling Road (Route 638) as discussed in Appendix A. To generate a forecast, the research team applied the Fratar method twice: once with perfected observed link volumes, and once where forecast year link volumes had an average forecast error of 12.22% based on one source from the literature (Buck and Sillence, 2014). Because this was not a true forecast but rather was used for illustrative purposes only in Appendix A, the accuracy of this technique was not reported in Table 3 in the body of this report.

38. *The BJ's Wholesale Club Traffic Impact Assessment* (VHB, 2007) forecast 2009 peak hour volume presuming the store opened for business by 2009. The occupancy permit issued on November, 12, 2008 (Smidler, 2015), and a telephone call from the research team to the

office of the wholesale club (May 28, 2015) both indicated an opening in November 2008. Because VDOT did not have 2009 volumes for this location, 2010 volumes were used for 9 of the 10 links in the study. An exception, however, was Starling Drive, which is maintained by Henrico County (Jones, 2015a). The forecast build volume was obtained by summing the background no-build volume for 2009 and the "site volume" generated by the new development. For example, during the peak hour, the no build forecast volume in 2009 for Starling Drive, which is close to the north driveway of BJ's Wholesale Club, was 828. Since the study showed turning movement at several intersections, all the northbound (293), southbound (487), and turning volumes (0, 12, 12, and 24) to and from the traffic counter (located at the south side of north driveway) were summed to generate the link volume of 828 for Starling Drive. Based on the study, site volumes were generated by some percentage of the total entering traffic of 285 for the weekday PM peak hour. The total site volume (256) was thus determined by adding two directional percentages (40% each) and two turning percentages (5% each), the total of which (90%) is multiplied by 285 to get roughly 256. Therefore, the study forecast the total peak hour volume for Starling Drive for 2009 as (828 + 256) = 1,084. The hourly observed count for Starling Drive for 2010 was requested from the Henrico County Traffic Division (Smidler, 2015) to compare with the forecast peak hour volume. Because the count from Starling Drive was an unadjusted temporary count, the observed peak hour volume was determined by adjusting the raw hourly count from Starling Drive with the seasonal factor. For example; the raw vehicle count for Starling Drive was taken on a Monday in August. The seasonal factor for August for Parham Road was 0.89006881 (since Starling Drive is not in VDOT's TMS database, the seasonal factor for the adjacent Parham Road was used [Jones, 2015b]). The peak month seasonal factor was 0.86505691 (in this case, November was taken as the peak month, which had the third highest volume for Starling Drive, but this month may vary by link). Thus the peak hour observed volume for Starling Drive was determined as 954 (927 * 0.89006881/0.86505691). However, 3 of the 10 links did not have a seasonal factor for 2010. Therefore, the seasonal factor for 2011 was applied. For some links, it was also necessary to use an axle factor to convert axles to vehicles; such factors were obtained from an internal application provided by Jones (2014).

39. *The Bell Creek Road Intersection Study* (Johnson, 2002) had three segments for which forecast and observed volumes could be obtained. Two forecasts, one for ADT and one for peak hour volume, were provided for two forecast years: 2003 and 2014. Four additional segments provided by the study were discarded. Bell Creek Road intersects Route 360 in two places such that there are four different locations on Route 360 for which there is a forecast: the area east of the eastern end of Bell Creek Road, the area west of the eastern end of Bell Creek Road, the area east of the western end of Bell Creek Road, and the area west of the western end of Bell Creek Road. As this was an intersection study, segment volumes were not the focus; rather, forecast-turning movements were used to infer a segment volume. All four of the Route 360 segment volumes noted here corresponded to a single observed volume (VDOT, 2004, 2015b), which was for Route 360 from I-295 to Lee Davis Road; this segment included both intersections noted previously. Because the February 14, 2002, cover memo for the study mentioned one of these four volumes, the research team chose this volume as the representative volume. After the three segments were discarded, there was a total of three that remained for this study. (Another segment—Sandy Lane north of Route

360—was discarded as the research team could not successfully align the segment as indicated in the study with the observed traffic counts available for 2003 and 2014.) Of interest, the DHVs (assuming they are peak hour volumes) showed mean absolute errors that were similar to those for the ADTs. For 2003, mean errors for peak hour and ADT were 86% and 88%, respectively; for 2014 these were 114% and 115%. A contributing factor appeared to have been that relative to Study 31, the forecast K-factors used in this study (0.10) did not deviate substantially from the observed K-factors (0.08 to 0.11 in 2003 and 0.10 in 2014).

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