TECHNICAL ASSISTANCE REPORT

WAYS TO ESTIMATE SPEEDS FOR THE PURPOSES OF AIR QUALITY CONFORMITY ANALYSES

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ABSTRACT

A *speed post-processor* refers to equations or lookup tables that can determine vehicle speeds on a particular roadway link using only the limited information available in a long-range planning model. An estimated link speed is usually based on volume, the percentage of heavy trucks, the free flow speed on the link, and the facility type (e.g., interstate, two-lane highway). These post-processed speeds are used to estimate motor vehicle emissions in conjunction with the U.S. Environmental Protection Agency's MOBILE model.

At least two post-processors in the form of software packages are available to VDOT staff. One, developed by Michael Baker Jr., Inc., can be used immediately with minor modifications as an interim measure to perform conformity analyses for new nonattainment areas. The other is being updated by VDOT's Northern Virginia District; a new generation is expected within a few months. Another option is for VDOT staff to code speed-volume equations directly into a spreadsheet, as has been done in the Appendix. The spreadsheet file is available internally in VDOT at \\501079whx18325\aircourse\hcmcurves.xls.

The authors recommend that over the next 12 months, either the Research Council, VDOT, or the two organizations work together to validate the post processors available by comparing their computed and actual speeds on a variety of facility types. In conjunction with this effort and to the extent that resources allow, the effect of different input data, such as vehicle age, vehicle type, and travel speeds, on mobile source emissions as predicted by the MOBILE model should be studied.

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INTRODUCTION

For metropolitan regions that are classified as maintenance or nonattainment, regulations driven by the 1990 Clean Air Act Amendment require Virginia to show that mobile source emissions from anticipated transportation projects are not expected to exceed a certain threshold. The computational method of determining projected emissions from future transportation projects is known as *conformity analysis*.

To perform a conformity analysis for a metropolitan region, VDOT hires consultants to do four major steps:

1. *Obtain predicted traffic volumes on each link in a roadway network* from a long-range travel demand model such as MINUTP, TP+, or TranPlan. A typical roadway network may range in size from approximately 1,000 links for the Roanoke area to tens of thousands of links for the Hampton Roads area. (Note that VDOT or VDOT consultants already run and maintain these long-range models.)

2. *Post-process* the travel demand model outputs to estimate accurate speeds on the roadway links. For each link, these speeds might include the morning peak hour speed, the evening peak hour speed, and an off-peak speed.

3. *Apply the U.S. Environmental Protection Agency's (EPA's) MOBILE model to determine emissions rates*, in the units of grams per vehicle per mile, for different speed classes (e.g., 0 to 5 mph, 5 to 10 mph) and different vehicle types (light-duty trucks, passenger cars, etc.). Thus VMT mix from step 1 along with the post processed speeds from step 2 are inputs for the MOBILE model. The outputs of this model are emissions rates.

4. *Obtain total emissions for a region* by multiplying the emissions rates from item 3 by VMT mix from item 1. This multiplication is done for each vehicle type and speed class. Two types of emissions, volatile organic compounds (VOCs) and nitrogen oxides (NO_x), are determined, with VOCs and NO_x being the key ingredients for the formation of ground level ozone.

VDOT has considered performing this analysis rather than hiring contractors to do the entire process. The responsibility for oversight of these four steps rests primarily with two VDOT divisions: the Environmental Division (ED) and the Transportation Planning Division (TPD). TPD has the responsibility for accomplishing item 1 through the use of staff and/or consultants, and the ED has indicated it has the staff capability to do items 3 and 4. The Virginia Transportation Research Council (VTRC) was asked by TPD and ED staff to help accomplish item 2—show how to create a post-processor for estimating travel speeds. VDOT ED staff indicated that a speed post-processor was needed by the end of 2002 (or earlier) so that conformity analysis can begin for new regions where such analysis will be required in 2003.

PURPOSE AND SCOPE

The purpose of this study was to identify or develop a prototype post-processor that VDOT staff could use to determine vehicle speeds for the purposes of conducting air quality conformity analyses. The post-processor had to meet two requirements:

1. *Speeds on the hundreds or thousands of individual links can be determined using data available from a typical long-range planning model*. Speeds are clearly computed at the planning level of analysis, suggesting that predicted speeds will not match observed speeds as closely as they would in the case of a design or operational analysis.

2. *The estimated speeds must be in a format suitable for use with the MOBILE model*, meaning that the speeds need to be stratified by time period (e.g., morning peak) and facility type (e.g., rural interstate, primary arterial).

This study did not seek to choose the best post-processor and thus does not necessarily suggest that VDOT use the same method statewide. Such a recommendation would be feasible only after a longer-term validation effort, which is recommended at the end of this document.

METHODS

Originally, the investigators intended to survey other states and develop a prototype post-processor. Shortly after the project began, however, two speed post-processors that already existed in VDOT were discovered. VDOT had already acquired one speed-based post-processor developed by Michael Baker Jr., Inc. for the ED in 2000, and the Northern Virginia District has been using a separate project-level post-processor since 1993. Thus three methods were used to learn how these two post-processors could be used immediately:

1. *Interview staff regarding how the post-processors function*. Multiple e-mails and telephone calls with E. A. Azimi and W. W. Mann (Northern Virginia Planning Section), A. A. Costello (ED), L.G. Franklin (formerly of the ED), J. A. Frazier and S. Sanagavarapu (Michael Baker Jr., Inc.), J. P. Ponticello (Department of Environmental Quality), and K. P. Spence (TPD) helped the investigators understand how the post-processors perform. A review by J. Byun of the Federal Highway Administration (FHWA) provided an understanding of how post-processing fits within the scope of conformity analysis.

2. *Replicate a subset of the computations of one of the speed post-processors.* To understand better how the speed post-processor used by the Central Office functions, an attempt was made to compute by hand the same speeds for interstate highway segments in the Roanoke area. Computations were not replicated for the Northern Virginia speed post-processor since the processor is currently not set up to process the thousands of links in a travel demand model automatically; however, such a modification may well be worthwhile as described at the end of this document.[*]

3. *Review accessible literature describing techniques for estimating link speeds at a planning level of analysis*. Several publications describe equations that can be used to estimate speeds from the limited information available in a regional travel demand model. These publications helped clarify the rationale behind the speed post-processors.

Information gleaned from the results of interviews, the effort to replicate the computations of one of the post-processors, and a review of the literature was synthesized into an explanation of how VDOT can use their Central Office speed post-processor to conduct air quality conformity analyses with the MOBILE6 model.

RESULTS

How the Central Office Speed Post-Processor Functions

Formally, VDOT has used at least two "central office post-processors." The first, entitled Post-Processor for Air Quality Analysis (PPAQ), is licensed to VDOT by Garmen Associates.[1] It performs speed post-processing and formatting of input files for the MOBILE model and is used for the Hampton Roads and Richmond areas. VDOT does not own this software and thus does not have the right to distribute it.

[*]E. A. Azimi of VDOT's Northern Virginia District has also developed a speed post-processor for air quality analysis. The speed post-processor differs from that developed by Michael Baker Jr., Inc., in at least two ways. First, it is more detailed, allowing the user to provide additional link-specific information, such as lane width, shoulder width, and number of access points. Second, the processor analyzes one link at a time rather than thousands of links in a batch mode. However, Northern Virginia District staff indicated a willingness to modify the post-processor to help perform emissions modeling if there is a need for this capability and subsequently pointed out that an update is expected in fall 2002.

A second processor, developed by Michael Baker Jr., Inc., is fully owned by VDOT. At one point, staff from the ED, the TPD, and Michael Baker Jr., Inc., collaborated on this post-processor to the extent that VDOT staff were heavily involved with the methodology, data, and logic used in the post-processor. The staff involved in developing the post-processor, however, moved on to other assignments or other positions, and a complete understanding of how the post-processor functions was not forthcoming from an examination of the processor's help file alone. Thus this report serves the role of documenting how the post-processor functions.

Overview

Depending on the size of the transportation region and the level of detail in the modeled roadway network, a regional model can have between 1,000 and 20,000 individual roadway links, where a link is simply a roadway segment between two points (e.g., a quarter-mile section of I-95 South between Exit 74C and Exit 75). A typical travel demand model provides 24-hour traffic volumes on each link and the proportion of vehicle miles traveled (VMT) for the entire region that occurs during the morning peak period, the evening peak period, and the off peak period.

The post-processor converts these 24-hour link VMTs to hourly volumes within each period, divides each link volume by the link's capacity, uses this ratio with a simple formula to estimate a link speed for each of the three periods, and then computes VMT and vehicle hours traveled (VHT) for each link and for each period. The approach followed by the Michael Baker Jr., Inc. post-processor for computing individual link speeds appears to match approaches given in the literature, at least for the case of undersaturated conditions.

The post-processor then aggregates link-specific volumes, speeds, VMT, and VHT by period and facility type and stores this information in a file. For example, this file shows the total volume, average speed, total VMT, and total VHT for all urban interstates in the Roanoke area during the morning peak hour. At this point, the speed post-processor ends. VDOT then uses vehicle composition observed by the Traffic Engineering Division to associate specific vehicle types (e.g., passenger cars, heavy trucks, motorcycles) with the aggregate volumes, speeds, VMT, and VHT from the speed processor.

Geographic Precision

Computations are aggregated by facility type in three distinct ways:

1. *Practical capacity* is the same for each facility type as opposed to each link. Using the I-95 example, there exists one practical capacity for "a lane of urban interstate," which is then be applied for all urban interstates in the region. This practical capacity is reduced in proportion to the percentage of heavy vehicles using the facility type.

2. *Link speeds, volumes, VMT, and VHT are aggregated by facility type.* The MOBILE model does not require as an input the speed, volume, VMT, and VHT for the one-quarter mile section of I-95 mentioned. Rather, an average speed, total volume, total VMT, and total VHT for "urban interstates" in a region are computed by the speed post-processor.

3. *FHWA vehicle types* (e.g., motorcycles, cars, buses) and the corresponding EPA vehicle types (e.g., LDGV, HDDV) are categorized by facility type. This computation is done outside the post-processor. For example, if sampling by the TED in Richmond showed that 85 percent of all vehicles on urban interstates are cars and 15 percent are trucks, the average speed, total volume, total VMT, and total VHT for "urban interstates" would be mapped to these cars and trucks.

Facility Types

These facility types, also known as functional classifications, are normally given within the transportation planning model. In addition, VDOT now makes functional classifications along with volume information available on its internal website currently at http://0501cotedweb1/tms/jsp/. Twelve facility types are used in the speed post-processor;[2] examples are shown for the Richmond and Albemarle County areas in Exhibit 1.

Inputs

The post-processor will work correctly only if it is installed using the executable setup file entitled *setup.exe*. There are then three critical input pieces to the post-processor:

- *Link-based input data file* in the form of a spreadsheet, where each line in the input data file corresponds to one link from the long-range travel demand model. A snapshot of just one line from a link input data file for the Roanoke area, entitled *roan90b.dbf* is shown here, where the travel demand model has provided the following information:

JUR	A	B	DIST	LANES	VOLUME	PEAK	AREA	FTYPE	VMT
770	477	603	1.54	3	24,387	2,439	1	11	37,556

This example is a link in the City of Roanoke (jurisdiction code 770), running on a map from coordinate A (477) to coordinate B (603). The link is 1.54 miles long; has three lanes; and has a 24-hour volume of 24,387 vehicles, 2,439 of which traverse the link during its highest hour of travel. The link is an urban interstate (facility type 11), and if the 24,387 vehicles are multiplied by the 1.54-mile distance, 37,556 VMT is obtained during a 24-hour period.

Exhibit 1. Examples of Facility Types

Facility Type	Two-Digit Code in Post-processor	Albemarle County Area	Richmond Area
Rural Interstate	01	I-64 in Albemarle County	I-95 in Hanover County
Rural Principal Arterial	02	Route 29 south of Charlottesville	Route 360 (Hull Street Road) in Chesterfield County
Rural Minor Arterial	06	Route 250 West Route 240	Patrick Henry Road in Hanover County
Rural Major Collector	07	Route 601 (Old Ivy Rd) Route 637 (Dick Woods Road)	Winterfield Road in Powhatan County
Rural Minor Collector	08	Advance Mills Road between Buck Mountain Road and Frays Mountain Road	Route 684 in Powhatan County between U.S. 60 and Route 625
Rural Local	09	Dry Bridge Road	Three Bridge Lane in Powhatan County
Urban Interstate	11	I-64 (a 0.17 mile section is within Charlottesville City limits)	I-95 in Richmond
Urban Freeways and Expressways	12	Route 250/29 Bypass	Chippenham Parkway
Urban Other Principal Arterials	14	Route 29 North from Charlottesville to Rio Road	250 (Broad Street) from U.S. 33 (Staples Mill Road) to 21st Street
Urban Minor Arterial	16	Barracks Road, Stony Point Road (Route 20)	250 (Broad Street) from 21st Street to 23rd Street
Urban Collector	17	Rio Road East Old Ivy Road Georgetown Road	Providence Road and Buford Road from U.S. 60 to Pinetta Drive
Urban Local	19	Oak Tree Lane	Perrymont Road in Chesterfield County

Since the Roanoke travel demand model has about 983 links in the network, this *roan90b.dbf* file has 983 lines organized in the manner shown previously. Further, the *clinks* table shown in the file *VDOTspd.mdb* shows this same information.

- *Facility type input data table*, where each line in the table corresponds to a particular facility type in a region. The *CtyLookUp* table in the file *VDOTspd.mdb* contains one line for each facility type in a region. A snapshot of Roanoke's *CtyLookUp* table is shown here, where capacity information is summarized for all interstate facilities (facility type 11) for the City of Roanoke (jurisdiction code 770). According to this software, a lane of these interstates has a practical capacity of 1,440 passenger cars per hour per lane and a free flow speed of 59.9 mph.

Jur	COUNTY	Region	Ftype	Capacity	LANES	FFSPEED	GROWTH	TRUCKS	Interstate
770	Roanoke City	Roanoke	11	1440	2	59.9	0.0187	0.085	Yes

Capacity is formally defined in the *Highway Capacity Manual* (HCM) as the maximum flow rate or the maximum number of passenger cars per hour per lane that can pass an observer at Level of Service (LOS) E.[3] For an interstate facility with a 60 mph free flow speed, this value is 2,300. Yet the original Bureau of Public Roads (BPR) equations used *capacity* to denote *practical capacity*, which has been defined as 80 percent of the actual capacity or implied to be the saturation flow rate corresponding to LOS C.[4,5] According to the 1998 HCM, LOS C for an interstate with a 60 mph free flow speed is exactly 1,440.[6] Thus the 1,440 figure appears to be based on the definition of *practical capacity*.

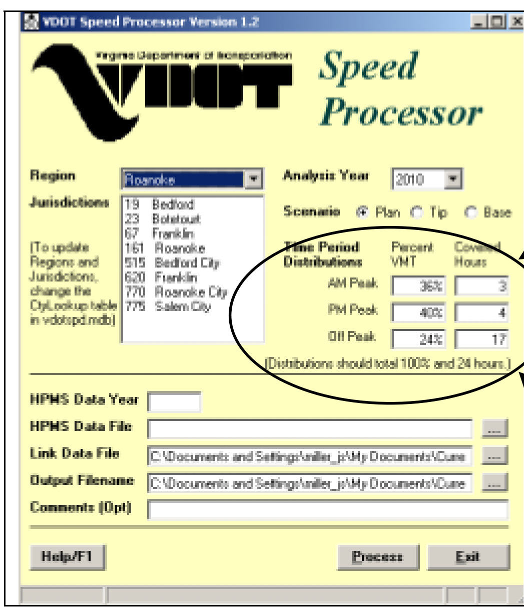
The far right columns in this table explain that the traffic stream using Roanoke urban interstates are composed of 8.5 percent heavy trucks. As explained in the help file associated with the post-processor, capacity is thus reduced to account for these trucks, using the HCM approach of

$$Capacity = \frac{Ideal\ Capacity}{1 + (Truck\ Weighting\ Factor - 1)(Percent\ Trucks)} = \frac{1{,}440}{1 + (1.5 - 1)(.085)} = 1{,}381 \quad \text{(Eq. 1)}$$

In one sense, this approach is incongruent with theory, since the HCM defines capacity as LOS E whereas the equation above appears to use "capacity" in reference to LOS C.[3] On the other hand, it can be argued that at the planning level of analysis where a single average number is used to represent the capacity of all links of a particular facility type, the error introduced by this truck weighting technique is thus relatively small.

- *Temporal VMT distribution.* The data entry screen in Exhibit 2 that users first see when they activate the post-processor by starting the file *VDOTspd.exe* shows that users must enter the percentage of VMT that occurs during the morning peak,

Exhibit 2. Initial Data Entry Screen for Central Office Speed Post-processor



The time period distributions shown to the right of the input screen:

-- percentage of VMT that occurs during the morning, evening, and off peak periods,

-- duration of the morning, evening, and off peak periods

are also shown in the *EntryScreenData* table in the file *VDOTspd.mdb* as the fields

-- PkPercAM, PkPercPM, PkPercOff, and

-- PkHourAM, PkHourPM, and PkHourOff

evening peak, and off peak periods for the *entire region*. Typically, these values would come from either the assumptions used in the travel demand model or knowledge of travel behavior in the area.

Computations Performed

The post-processor takes each link volume for each time period from the link data file (e.g., *roan90b.dbf*); divides it by each appropriate capacity for the link type (e.g. from the *CtyLookUp* table within the file *VDOTspd.mdb*); and then computes a volume, VMT, speed, and VHT for each link and each time period. Unfortunately, the user does not see these individual link-based speed results directly. Instead, the unseen link results are then aggregated by facility type and time period.

For example, for Roanoke, since there are 10 facility types, there will be 10 lines shown in the *SpeedResults* table of the file *VDOTspd.mdb*, with total VMT, total volume, total VHT, and average speed shown for each facility type, stratified by AM peak, PM peak, and off peak time periods. A spreadsheet-based output file, *Roan15t.xls* file, is produced with identical information but organized slightly differently, with one row for each facility type and time period.

Conceptually the post-processor is simple, but the details can be a bit tedious. To illustrate how it functions, the Roanoke database was modified such that there are only two roadway segments, or links, of facility type "rural Interstate." This exercise focuses on just those two links, designated as the "upper link" and "lower link" in Exhibit 4.

Exhibit 3 shows the *input* data stored in *VDOTspd.mdb* and the link input file for Roanoke. The top tier of data is specific to the links, the middle tier is specific to the facility type (e.g., rural interstates), and the bottom tier applies to the entire region of Roanoke.

Exhibit 3. Example Roanoke Input Data

From the clinks table of VDOTSPD.mdb or roan90bR.dbf: these two lines give link specific information

JUR	FTYPE	ATYPE	DIST	VOLUME	VMT	LANES
770	11	1	1.54	24,387	37,556	3
770	11	1	1.54	24,453	37,658	3

3 lanes for these interstate links. Use this number to compute speed.

From the CtyLookUp table of VDOTSPD.mdb -- this line gives facility type information

Jur	COUNTY	Region	Ftype	Capacity	LANES	FFSPEED	GROWTH	TRUCKS	Interstate
770	Roanoke City	Roanoke	11	1,440	2	59.9	0.0187	0.085	Yes

From the EntryScreen table of VDOTSPD.mdb--this line gives regional information

Do not use this number in the speed computations.

PkPercAM	PkPercPM	PkPercOff	PkHourAM	PkHourPM	PkHourOff
36%	40%	24%	3	4	17

Speeds, VMT, VHT, and volumes are computed using seven steps:

1. *For each link, convert the 24-hour volume into an average hourly lane volume for the AM peak period, the PM peak period, and the off-peak period.* This conversion is accomplished by multiplying each 24-hour link volume by the regional percentages shown at the bottom of Exhibit 3 (e.g., 36 percent of all Roanoke travel occurs during the morning peak, so 36 percent of the 24,387 vehicles on the upper link travel during this morning peak). Then, these time period volumes are divided by the number of hours in each time period (3, 4, and 17), and then these hourly volumes are divided by the number of lanes (3) to obtain a lane volume for each link. Exhibit 4 illustrates these computations.

Exhibit 4. Example of Conversions from 24-Hour Volumes to Hourly Volumes

A	**AM Period Total Volume (36%)**	**PM Period Total Volume (40%)**	**Off Peak Period Total Volume (24%)**
Upper link	8,779	9,755	5,853
Lower link	8,803	9,781	5,869

B	**AM Period Hourly Volume (Averaged Over 3 Hours)**	**PM Period Hourly Volume (Averaged Over 4 Hours)**	**Off Peak Period Hourly Volume (Averaged Over 17 Hours)**
Upper link	2,926	2,439	344
Lower link	2,934	2,445	345

C	**AM Period Hourly Volume (Divided Over 3 Lanes)**	**PM Period Hourly Volume (Divided Over 3 Lanes)**	**Off Peak Period Hourly Volume (Divided Over 3 Lanes)**
Upper link	975	813	115
Lower link	978	815	115

2. *Compute the actual practical capacity for each lane to account for the presence of trucks*. Using the approach from Eq. 1, the speed post-processor should translate the practical capacity of a single lane of rural Roanoke interstate from 1,440 passenger car equivalents to 1,381 vehicles, given that 8.5 percent of these vehicles will be heavy trucks.

3. *Compute the v/c ratio for each link for each time period*. The hourly lane volumes shown in Exhibit 4c are divided by the capacity for this facility type (1,381) to compute a v/c ratio for each time period as shown in Exhibit 5.

Exhibit 5. Volume to Practical Capacity Ratio for Each Interstate Link

Link	AM Period	PM Period	Off Peak Period
Upper link	0.71	0.59	0.08
Lower link	0.71	0.59	0.08

4. *Compute the average travel time during each time period for each link*. The formula employed by the post-processor is a variant of the type based on the BPR. The formula appears to be the following for interstate facilities:

   When the v/c ratio is less than 1.0, the interstate travel time is

   $$Travel\ time = Uncongested\ Travel\ Time\left[1 + 0.15(v/c)^{13.29}\right] \quad \text{(Eq. 2)}$$

   For example, for the upper link with an off period peak *v/c* ratio of 0.08, the link travel time is shown in Exhibit 6 as

   $$Travel\ time = \frac{1.54 miles}{60 mi/h}\left[1 + 0.15(0.08)^{13.29}\right] = 0.0257\ hours \quad \text{(Eq. 3)}$$

   When the v/c ratio is greater than 1.0, the interstate travel time is computed using a formula given in the help file as

   $$Travel\ time = Uncongested\ Travel\ Time\left[1 + 0.15(v/c)^{13.29}\right] + \frac{0.4(v-c)}{2c} \quad \text{(Eq. 4)}$$

   In applying the equation, the help file indicates that the *v/c* ratio should be set to 1.0. This equation thus reduces to

   $$Travel\ time = Uncongested\ Travel\ Time\,[1.15] + \frac{0.2(v-c)}{c} \quad \text{(Eq. 5)}$$

   For example, if a link had an AM period *v/c* ratio of 1.06, the travel time would be

   $$Travel\ time = \frac{1.54 miles}{60 mi/h}[1.15] + \frac{0.2(1{,}463 - 1{,}381)}{1{,}381} = 0.0414\ hours \quad \text{(Eq. 6)}$$

Exhibit 6. Travel Times on Interstate Links (Hours)

Link	AM Period	PM Period	Off Peak Period
Upper link	0.02575	0.02571	0.02571
Lower link	0.02575	0.02571	0.02571

5. *Compute the resultant average speed for each link.* The link distance (in this case, 1.54 miles) is divided by the travel times to obtain an average speed for each time period, as shown in Exhibit 7.

Exhibit 7. Average Travel Speeds on Each Link for Each Time Period (mph)

Link	AM Period	PM Period	Off Peak Period
Upper link	59.8	59.9	59.9
Lower link	59.8	59.9	59.9

6. *Compute the link VHT.* The VMT for each link is computed by multiplying the volumes from Exhibit 4a by the link distance of 1.54 miles, and then these VMT are divided by the link speeds to obtain VHT. For example, Exhibit 4a showed a total of 8,779 vehicles that used the upper link during the AM peak. Multiplying this figure by 1.54 miles and then dividing by a speed of 59.8 mph means that the AM peak period accounts for approximately 226 VHT, as summarized in Exhibit 8. (Some rounding has been used in this example.)

Exhibit 8. Vehicle Hours Traveled for Each Link and Time Period

Link	AM Period	PM Period	Off Peak Period
Upper link	226.0	250.8	150.5
Lower link	226.7	251.5	150.9

7. *Aggregate the totals by facility type.* The post-processor does not show the individual link computations featured in Exhibits 4b through 8. Instead, it gives the total volume, total VMT, average speed, and total VHT for the various facility types and time periods, an example of which is illustrated in Exhibit 9. (This is obtained by adding individual link VHT values from Exhibit 8 for each facility type.) Thus VHT can be associated with a specific average speed.

Exhibit 9. Aggregate Vehicle Hours Traveled for Rural Interstate Facility Type

Results	AM period (average speed 59.8 mph) (speed class 56-60 mph)	PM period (average speed 59.9 mph) (speed class 56-60 mph)	Off peak period (average speed 59.9 mph) (speed class 56-60 mph)
Computed by hand	452.7	502.3	301.4
From post-processor	452.0	502.3	301.4

Exhibit 9 shows that the results computed by hand match the results computed by the post-processor for this simple example.

Output

The post-processor reports total volume, total VMT, average speed, and total VHT by facility type (urban interstate, urban principal arterial, etc.) and within that category by time period (AM peak, PM peak, and off peak, the sum of which yield 24 hours).

This output information is reported in two places: the *SpeedResults* table of the file *VDOTspd.mdb* and an Excel data file specified by the user, such as *Roan15T.xls*. The excerpt of this output pertaining to the two Roanoke interstate links is shown in Exhibit 10.

Exhibit 10. Post-Processed Speeds for Rural Interstates

JUR	ATYPE	FTYPE	TIME	VOL	VMT	VHT	SPD	Description
770	1	11	0	48,840	75,214	1,256	59.9	24-hour total
770	1	11	1	17,582	27,077	452	59.9	AM peak
770	1	11	2	19,536	30,086	502	59.9	PM peak
770	1	11	3	11,722	18,051	301	59.9	Off peak

In Exhibit 10, time period 0 is the 24-hour total, whereas time periods 1, 2, and 3 are the AM peak, PM peak, and off peak values, respectively.

In the *CtyLookup* table in *VDOTspd.mdb*, the two fields (number of lanes and free flow speeds) are reversed (e.g., 40 lanes and a free flow speed of 2 mph are shown for one facility). Staff at Michael Baker Jr., Inc. indicated that this is a minor flaw that should not affect the calculations.

Associating Link Speeds with Vehicle Classes

After the post-processor is run, one has an estimate of volume, VMT, speed, and VHT by facility, but one does not know how the post-processor outputs relate to the 16 vehicle categories used in MOBILE6. MOBILE6 actually has 28 vehicle categories for use with other aspects of the software, but for the purposes of classifying travel by vehicle class, one needs to focus on only the 16 "combined vehicle classes." VDOT has at least three options for connecting these speed post-processor outputs to the 16 MOBILE6 vehicle categories:

1. *For new areas where no MOBILE model is in place*, the simplest option may be to look at traffic engineering data. For example, Virginia traffic counts on the Roanoke interstates might show that 10 percent of all vehicles are heavy trucks for Roanoke interstates generally. Exhibit 11 shows that "heavy trucks" refer to eight different vehicle categories in MOBILE6. Thus one way to allocate the 18,051 VMT shaded in Exhibit 10 is to combine this Roanoke-specific observation with EPA's national defaults, which include the fact that 32.46 percent of all heavy vehicles nationally are classified as HDV2B.[7] The computations are thus:

- 10% of this 18,051 VMT = 1,805 VMT assigned to heavy trucks in the Roanoke area

- 32.46% of this heavy truck VMT = 586 VMT assigned to MOBILE6 type HDV2B.

A similar procedure can thus be followed for the 15 other vehicle categories in MOBILE6 and the other facility types.

2. *In areas where detailed vehicle type data are available*, VDOT does not have to use national defaults but instead could substitute DMV registration data for the percentages. A set of frequently asked questions addressed by EPA staff points out that states always have the option of providing additional detail beyond that required by EPA.[8] In fact, MOBILE6 guidelines suggest that for nonattainment areas "EPA expects states to develop and use their own specific estimates of VMT by vehicle class."[9] Such estimates would presumably come from typical traffic counts (mentioned in the bullet) and DMV registration data (mentioned herein). The TPD pointed out that VDOT and DEQ staff worked together to compute VMT mix for the new nonattainment areas using DMV data.

3. *For areas where MOBILE5 models are already in place*, VDOT may consider converting from the eight MOBILE5 vehicle classes to the 16 MOBILE6 vehicle classes, following a procedure described by the EPA.[9] Exhibit 11 shows a linkage between FHWA/TED vehicle types, MOBILE5 vehicle types, and the combined MOBILE6 classes.

Matching FHWA Functional Classifications to EPA Functional Classifications

EPA guidance notes that MPOs and state DOTs will have information enabling one "to determine the proportion of vehicle VMT by time of day and facility class."[9] In most areas of the state, VDOT's VMT allocations will be no more precise than the functional classifications shown in Exhibit 1. In that instance, the EPA's guidance may be used for linking VDOT facility types to EPA facility types as reflected in Exhibit 12.

Role of HPMS Data

If every physical road segment was included in the road network, then one could simply use the link data file described. Local roads, however, are often not included in the roadway network, yet their vehicles obviously affect emissions. One simple way to include the effect of road segments that are not part of the modeled roadway network is to use data from the Highway Performance Monitoring System (HPMS), which are similar to the link data shown previously. Exhibit 2 shows that an HPMS data file can be included to provide information for these local roads.

Exhibit 11. MOBILE6, MOBILE5, and FHWA/TED Vehicle Classifications[9,2]

No.	Description	MOBILE6 Classification	MOBILE5 Classification	FHWA/TED Classification
1	Light-Duty Vehicles (Passenger Cars)	LDV	LDGV, LDDV	Passenger Cars
2	Light-Duty Trucks 1 (0-6,000 lb GVWR, 0-3750 lb LVW)	LDT1	LDGT1,LDDT	Other 2-Axle, 4-Tire Vehicles
3	Light Duty Trucks 2 (0-6,001 lb GVWR, 3751-5750 lb LVW)	LDT2	LDGT1, LDDT	
4	Light Duty Trucks 3 (6,001-8500 lb GVWR, 0-5750 lb ALVW)	LDT3	LDGT2, LDDT	
5	Light Duty Trucks 4 (6,001-8500 lb GVWR, >5750 lb ALVW)	LDT4	LDGT2, LDDT	
6	Class 2b Heavy Duty Vehicles (8501-10,000 lb GVWR)	HDV2B	HDDV, HDGV	Heavy Trucks
7	Class 3 Heavy Duty Vehicles (10,001-14,000 lb GVWR)	HDV3		
8	Class 4 Heavy Duty Vehicles (14,001-16,000 lb GVWR)	HDV4		
9	Class 5 Heavy Duty Vehicles (16,001-19,500 lb GVWR)	HDV5		
10	Class 6 Heavy Duty Vehicles (19,501-26,000 lb GVWR)	HDV6		
11	Class 7 Heavy Duty Vehicles (26,001-33,000 lb GVWR)	HDV7		
12	Class 8a Heavy Duty Vehicles (33,001-60,000 lb GVWR)	HDV8A		
13	Class 8b Heavy Duty Vehicles (>60,000 lb GVWR)	HDV8B		
14	School Buses	HDBS	HDDV, HDGV	Buses
15	Transit and Urban Buses	HDBT		
16	Motorcycles (All)	MC	MC	Motorcycles

Exhibit 12. Relationship Between VDOT Facility Types and EPA Facility Types[9*]

VDOT Facility Type	EPA Facility Type
Rural Interstate	Freeway And Freeway Ramp[†]
Rural Principal Arterial	Freeway And Freeway Ramp
Rural Minor Arterial	Arterial/Collector
Rural Major Collector	Arterial/Collector
Rural Minor Collector	Arterial/Collector
Rural Local	Local Roadway
Urban Interstate	Freeway And Freeway Ramp
Urban Freeways and Expressways	Freeway And Freeway Ramp
Urban Other Principal Arterials	Arterial/Collector
Urban Minor Arterial	Arterial/Collector
Urban Collector	Arterial/Collector
Urban Local	Local Roadway

[*]Adapted from *Technical Guidance on the Use of MOBILE6 for Emission Inventory Preparation* (Table 4.2.1).

[†]EPA guidance notes that freeway and freeway ramp categories are aggregated, noting that "By default in MOBILE6, 8% of VMT in any freeway and freeway ramp category will be the freeway ramp VMT. For example, if the urban interstate category has a VMT fraction of 10%, a MOBILE6 VMT for this roadway grouping would be 0.8% (8% of the 10%) freeway ramp and 9.2% (10%-0.8%) freeway without ramps."[9] The guidance gives states the option, however, of splitting up ramp and freeway VMT.

Planning-Level Alternatives for Estimating Speeds

In 1997, a report funded by FHWA's Travel Model Improvement Program published a synthesis of techniques for estimating speeds for the purposes of conformity analysis, where speeds must be forecast on a large number of highway links with limited geometric and volume data.[5] Techniques for the explicit purpose of estimating speeds based on volumes included updates to the BPR equation, an Akcelik/Davidson formula based on queuing theory, an adaptation of the HCM by Horowitz, a Surface Transportation Efficiency Analysis Model (STEAM) developed by Cambridge Systematics, and a proprietary package by TMODEL corporation.[4,5] At that time, the report recommended that agencies focus on the first two possibilities and consider the third possibility as information became available. Because the BPR updates require fewer parameters than the Horowitz updates without any documented impact on performance, it would seem that the first two approaches are preferable; however, Horowitz's curves have been used in practice and are exemplified in an Asheville, North Carolina case study.[10]

- *Updated BPR technique*

$$speed\ \ for\ signalized\ \ facilities = \frac{free\ \ flow\ speed}{1+0.05(v/c)^{10}} \qquad \text{(Eq. 7a)}$$

$$speed\ \ for\ unsignalized\ \ facilities = \frac{free\ \ flow\ speed}{1+0.20(v/c)^{10}} \qquad \text{(Eq. 7b)}$$

Capacity refers to the HCM capacity (e.g., the flow at LOS E).

- *Akcelik/Davidson approach* (for a 1-hour flow)

$$speed\ \ for\ \ any\ \ facility = \frac{1}{t_0 + \left\{0.25\left[(v/c)-1+\sqrt{((v/c)-1)^2+16(v/c)(t_c-t_0)}\right]\right\}} \qquad \text{(Eq. 8)}$$

t_0 is the time it takes to travel 1 mile under free flow conditions

t_c is the time it takes to travel 1 mile at capacity

Capacity refers to the HCM capacity (e.g., the flow at LOS E).

- These may be contrasted with the approach used in the *VDOT post-processor* (which was rewritten in the same form as Eqs. 7 and 8):

$$speed\ for\ understatured\ interstates = \frac{free\ flow\ speed}{1 + 0.15(v/c)^{13.29}}$$ (Eq. 9a)

$$speed\ for\ understatured\ non-interstates = \frac{free\ flow\ speed}{1 + 0.8(v/c)^{2}}$$ (Eq. 9b)

$$speed\ for\ oversatured\ interstates = \frac{Length\ of\ link}{Uncongested\ travel\ time\ [1.15] + \frac{0.2(v-c)}{c}}$$ (Eq. 9c)

$$speed\ for\ oversatured\ non\text{-}interstates = \frac{Length\ of\ link}{Uncongested\ travel\ time\ [1.8] + \frac{0.2(v-c)}{c}}$$ (Eq. 9d)

Capacity is thought to refer to the practical capacity (e.g., the flow at LOS C).

- *Horowitz's modifications to the BPR*

$$speed\ for\ 70\ mph\ facilities = \frac{free\ flow\ speed}{1 + 0.88(v/c)^{9.8}}$$ (Eq. 10)

The shaded coefficient of 0.88 and the exponent of 9.8 in Eq. 10 are changed for other types of facilities as shown in Exhibit 13.[10] Capacity refers to LOS E.

Exhibit 13. Parameters for Horowitz's Technique[10*]

Facility	Coefficient	Exponent
70 mph freeway	0.88	9.8
60 mph freeway	0.83	5.5
50 mph freeway	0.56	3.6
70 mph multilane facility	1.00	5.4
60 mph multilane facility	0.83	2.7
50 mph multilane facility	0.71	2.1

**Source: NCHRP Report 365.*

In these techniques it is evident that assumptions for free flow speed and capacity will affect the validity of the equations, and it may be the case that the values chosen for free flow speed and capacity are as important as the formulation itself. Getting these two values correct is what one set of researchers called "the keys to success" when using BPR-based approaches.[4]

These techniques can be coded in the form of a spreadsheet or other software relatively easily. Two critical questions, however, are how well these techniques predict speeds, and to what extent accurate speed data affect emissions computations relative to the other input data, such as vehicle age. For unsignalized facilities, for example, a comparison of field data and modeled data showed that the "original" BPR equation had an approximately 30 percent root mean squared error, the updated BPR equations (Eqs. 7a and 7b) had a 12 percent error, and the 1994 HCM showed an 8 percent error.[5] To what extent do these error rates affect MOBILE emissions modeling?

Based on an analysis of MOBILE5, the literature suggests that errors in speed can affect VOC and NO_x emissions significantly, but the literature also cautions readers that the "directions of errors in individual input parameters are unpredictable.[11] For example, Exhibit 14, extracted from *NCHRP Report 394*, shows that an error for interstate speeds of 5 mph caused nitrogen oxide emissions to be in error by 16 percent whereas an error of 1 year in the median vehicle age caused the same NO_x emissions to be in error by 6 percent. For collector facilities, however, the effect of the 5 mph speed error was very small (0.4 percent) relative to the effect of the 1-year median age error (again, 6 percent).

Exhibit 14. Sensitivity of MOBILE5 to Changes in Input Data[11*]

Facility Type	Type of Error	Difference in Emissions Rates (%)	
		VOC	NO_x
Freeway	Speed	13	16
	Vehicle Type	-1	18
	Vehicle Age	8	6
Arterial	Speed	-7	3
	Vehicle Type	-4	-3
	Vehicle Age	-12	-9
Collector	Speed	17	0.4
	Vehicle age	8	6
	Cold Start Fraction	23	2

*Adapted from *NCHRP Report 394.*

CONCLUSIONS AND RECOMMENDED NEXT STEPS FOR VDOT

As shown here, the post-processor uses techniques that from inspection alone are somewhat comparable to those shown in the literature. In the absence of a validation effort, it cannot be shown that the post-processor performs any worse or any better than other techniques that use a similar level of data. Thus as of now three conclusions can be drawn.

1. *VDOT has the complete rights to a post-processor that can estimate speeds by facility type and time period*. As a short-term step to begin working on the conformity analyses that are required in the spring of 2003 for new nonattainment areas, VDOT's ED and TPD may begin to use and become refamiliarized with this post-processor. If this course of action is followed, four modifications should be made:

   - *Modify the processor to output the individual link computations*. The individual link speeds in Exhibits 4b through 8 are performed but not shown; only the average speeds by facility type in Exhibit 9 are given as output. Staff from Michael Baker Jr., Inc. indicated that they require 2 hours to modify the post-processor to give these individual link speeds.

- *Modify the number of lanes and free flow speeds columns*; as mentioned previously, the data shown in these two columns are reversed and this error should be corrected.

- *Update the capacities for interstate segments with values from the 2000 HCM*. The values shown in the file *VDOTspd.mdb* are based on the 1998 HCM and can be replaced with 2000 HCM values. The 2000 values are shown in Exhibit A1 of the Appendix.

- *Confirm with the consultant that the "capacity" used in the v/c ratio is the practical capacity and not the HCM capacity.* In reference to Exhibit 3, it was discussed that the Roanoke interstate capacity of 1,440 probably refers to practical capacity (based on LOS C) rather than the 2,300 figure that would be associated with LOS E. The *VDOTspd.mdb* file, however, showed interstates in other regions with capacities of 2,300. It is thought that these capacities were in error and that the practical capacity is the correct value; but this should be a statement the consultant can confirm. Although the Roanoke interstate has trucks, the trucks alone should not decrease its capacity from 2,300 to 1,440.

2. *Use this post-processor as a way to educate new VDOT employees who will be using the software*. For new nonattainment areas, such as Winchester, VDOT staff can use the existing post-processor, making three key changes to the inputs exemplified in Exhibit 3 assuming VDOT no longer has access to the original data files for the Winchester and Fredericksburg areas. If these data files can be found, VDOT may wish simply to update them in accordance with the 2000 HCM as described.

    - the *link-based input data file,* which is produced by the regional travel demand model and shows, for each link in the roadway network, the 24-hour volume and facility type. An example of this file is *roan90bR.dbf*.

    - the *facility type input data table,* which contains the capacity for each facility type in a region. These modifications would be made within the *CtyLookUp* table in the file *VDOTspd.mdb*.

    - the *temporal VMT distribution*, which is the percentage of VMT that occurs regionwide during the morning, evening, and off peak periods, which is given in the input data entry screen as shown in Exhibit 2 and is stored in the *EntryScreenData* table within the file *VDOTspd.mdb*.

Recommendations 1 and 2 presume that VDOT staff would use the post-processor already owned by VDOT and are meant to be relatively straightforward tasks that should not require much in the way of time or consultant expense. Should that prove not to be the case, VTRC or VDOT staff can code the four post-processor formulations (Eqs. 9a, 9b, 9c, and 9d) or the modified BPR formulations (Eq. 7) directly into a spreadsheet. This approach is illustrated in the Appendix.

3. *Recognize the need to preserve institutional memory through staff retention, documentation, or knowledge sharing*. The investigators and the current ED staff were not aware of two post-processors, and Northern Virginia staff had indicated they did not know about the central office efforts. One way to address this is through documentation: reports such as this may not be the most interesting reading but they serve as one way to preserve institutional memory despite personnel turnover. A second instrument would be periodic updates or information sharing: for example, given that VDOT's Northern Virginia District expects to have its post-processor updated in 3 months, a November meeting of district, ED, and TPD staff should be held, and the result may be that the Northern Virginia District's post-processor is recognized as one that can be used statewide. Even if such a decision is not made, the information sharing from such a meeting should be productive.

RECOMMENDED NEXT STEPS FOR THE VIRGINIA TRANSPORTATION RESEARCH COUNCIL

There are three courses of action that can be pursued concurrently over the next year, depending on which of these will be most useful to VDOT.

1. *Determine the sensitivity of the MOBILE models to various inputs.* VTRC can conduct research across four key areas to determine the efficacy of making improvements to the various inputs in the MOBILE model. Specifically, the sensitivity of the MOBILE6 model to these four items should be addressed:

   - *Vehicle classifications*. To what extent will more accurate data on the age of vehicles as well as the traffic engineering classifications described in Exhibit 11 affect emissions computations? An FHWA representative, for example, pointed out that NO_x emissions are especially sensitive to the proportion of diesel vehicles traveling at high speeds, with 6 to 7 percent of all vehicles generating 40 to 50 percent of all mobile source NO_x emissions.

   - *Predicted speeds*. Although the MOBILE6 model uses speed classes of 5 mph, DEQ staff point out that more accurate speeds could significantly affect emissions. The question is *to what extent* more accurate speed predictions affect emissions computations?

   - *Geographic aggregation*. To what extent will performing this level of analysis at a finer geographic level of detail than facility type affect emissions computations? This question directly affects the use of various data sources (HPMS, the VDOT SHIPS planning data base, and local count data) for estimating "off network" VMT from local roads.

- *Temporal aggregation*. Would the use of finer time increments than is currently the case, such as hourly travel levels, significantly affect estimated emissions rates? To that extent, a spreadsheet that used 24 periods of 1 hour each, rather than just three periods as reflected in Exhibit 2, could use hourly volumes rather than multi-hour volumes to forecast speeds.

Certainly a logical extension of this report is assessing the extent to which speeds predicted by a variety of techniques reflect field data, and to that extent some quick research may be undertaken. At this point, however, it is not yet clear whether a substantial amount of resources are better spent refining speed estimates as opposed to refining estimates of vehicle classes or other MOBILE input data. The literature is certainly not silent on this topic but rather notes that there are problems with all four data categories shown above; further, methods used for assessing MOBILE5 sensitivity should be a reasonable starting point for assessing MOBILE6 sensitivity.[11] Because the findings of this work may lead to recommended changes in how up to three distinct software efforts are undertaken, i.e., the urban travel demand model, the speed post processor, and the MOBILE model, it would be appropriate to consult with ED and TPD staff regarding which areas are most productive for exploring.

2. *Look at techniques to validate and improve the predictions of speeds. Evaluate the accuracy of the different speed estimation techniques by comparing predicted values to field data*. Potential changes to the speed post-processor include the parameters in Eqs. 7 through 10, the values used for the free flow speed and capacity in those equations, and as mentioned by an FHWA representative, the use of equations shown in the HCM. The Appendix illustrates that assumptions regarding capacity and facility type are important regardless of the post-processor that is chosen, which in turn highlights the role of a validation effort described here. The outcome of such a research effort could be used to develop an entirely new processor or to update an existing one. Potential data sources include the Northern Virginia and Hampton Roads Smart Traffic Centers, manual efforts, the VTRC smart travel van, and as suggested by VDOT staff, commute times in the Northern Virginia area reported by the U.S. Census, which will be available in spring 2003. Two intriguing advantages of the Census approach are the availability of longitudinal data and the availability of data where the v/c ratio is greater than 1.

3. *Automate the MOBILE input files to the extent possible. Develop automated processes for importing the link-based output file from regional travel demand modeling software (such as MINUTP or TP+) into the speed post-processor and generating an input file for MOBILE6 based on Virginia data.* Given that DEQ and VDOT have made previous efforts in this direction, VTRC would want to learn more about what the scope of this third effort should be before proceeding. One simple modification, for example, would be to convert the three periods of current speed classifications (AM peak, PM peak, and off peak) to 24 periods, each 1 hour long, using hourly variations in travel as recorded by VDOT traffic count data.

REFERENCES

1. Garmen Associates. *PPAQ: Post-processor for Air Quality Analysis, Version 3.1.* Montville, N.J., 1994.

2. Michael Baker Associates. Draft Report Detailing 1999 Traffic Trends and Characteristics for the Richmond and Hampton Roads Areas. Richmond, Virginia, circa 2000 (available from the VDOT Environmental Division).

3. Transportation Research Board. *Highway Capacity Manual*. Washington, D.C., 2000.

4. Dowling, R., Kittelson, W., and Zeeger, J. *NCHRP Report 387: Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*. Transportation Research Board, Washington, D.C., 1997.

5. Dowling Associates. *Travel Model Speed Estimation and Post Processing Methods for Air Quality Analysis.* U.S. Department of Transportation, Washington, D.C., 1997.

6. Garber, N.J. and Hoel, L.A. *Traffic and Highway Engineering.* Revised Second Edition. PWS Publishing, Pacific Grove, Calif., 1999.

7. Environmental Protection Agency. National Vehicle and Fuel Emissions Laboratory. *User's Guide to MOBILE6.0: Mobile Source Emissions Factor Model.* Ann Arbor, 2002. Viewed at http://www.epa.gov/otaq/m6.htm on June 24, 2002. (See Appendix D, Vehicle Class Adjustment Factors, Part 2, p. 202).

8. Environmental Protection Agency. *Frequently Asked Questions on MOBILE6*. Viewed at http://www.epa.gov/otaq/m6.htm on June 21, 2002.

9. Environmental Protection Agency. National Vehicle and Fuel Emissions Laboratory. *Technical Guidance on the Use of MOBILE6 for Emission Inventory Preparation*, Ann Arbor, Michigan, 2002. Viewed at http://www.epa.gov/otaq/m6.htm on June 21, 2002. (See Table 4.2.1.)

10. Martin, W.A., and McGuckin, N.A. *NCHRP Report 365: Travel Estimation Techniques for Urban Planning.* Transportation Research Board, Washington, D.C., 1998.

11. Chatterjee, A., Miller, T.L., Philpot, J.W., Wholley, T.F., Guensler, R., Hartgen, D., Margiotta, R.A., and Stopher, P.R. *NCHRP Report 394: Improving Transportation Data for Mobile Source Emission Estimates*, Transportation Research Board, Washington, D.C., 1997.

APPENDIX: A POST-PROCESSOR BASED ON THE 2000 HCM

This report illustrated three possible post-processors that VDOT may use—one developed under contract for the Central Office (Eq. 9), one developed in the literature (Eq. 7), and an existing processor developed by VDOT's Northern Virginia District that is currently being modified. This appendix illustrates a fourth possibility: replicating the year 2000 version of the HCM. Although the HCM approach is promising, the details that follow illustrate how assumptions will heavily influence any method for estimating travel speeds. Thus it appears that it is most productive for VDOT to begin using any one of the four post-processors as an interim step quickly and then over the coming year to begin to compare predicted speeds with actual speeds that are suggested in Recommendation 2.

Comparison of VDOT Facility Types and HCM Facility Types

Exhibit A1 compares the post-processor facility types, which are based on VDOT functional classifications, and the HCM classifications. Although the mapping is straightforward for an interstate facility, there are two or three possibilities for all other facility types. As shown in the right columns, the HCM classifications can be further subdivided based largely on free flow speeds. The capacities shown to the right require assumptions for the case of urban streets.

Exhibit A1. Comparison of HCM and Functional Classification Systems

Post-processor Facility Type	HCM 2000 Facility Type	HCM Page	Free Flow Speed (mph)	LOS E Capacity (pc/ph/pl)*	LOS C Capacity (pc/ph/pl)*
Interstate	Freeways	23-4	75	2,400	1,830
			70	2,400	1,770
			65	2,350	1,680
			60	2,300	1,560
			55	2,250	1,430
Arterial	Two-way highways (Class I) (1 lane each direction and signal spacing > 2 mi)	20-3,4	45-65	1,700	1,360**
	Multilane highways (signal spacing > 2 mi)	21-3	60	2,200	1,550
		21-3	55	2,100	1,430
		21-3	50	2,000	1,300
		21-3	45	1,900	1,170
	Urban Street Class I	10-6,10	50	1,140	930
	Urban Street Class II	10-6,10	40	890	670
	Urban Street Class III	10-6,10	35	850	480
	Urban Street Class IV	10-6,10	30	800	540
Urban Freeways and Expressways	Freeways	See HCM Freeways above			
	Multilane highways	See HCM Multilane highways above			
Collector	Urban street (if signal distance < 2 mi) or	See HCM Urban street above			
	Rural two-lane highway (Class II)	See HCM Two-way highways above			
Local	Not addressed	Assume speed of 25 mph			

*Capacity is shown as the number of passenger cars per hour per lane. LOS C refers to the "practical" capacity.
**The figure of 1,360 was estimated from 80% of the actual capacity.

The application of any post-processor with Exhibit A1 is a gross simplification of the details provided in the HCM; thus several caveats should be considered in future work.

- *Effect of congestion on travel speed*. Free flow speeds are observed at volumes below 1,300 passenger cars per hour per lane for interstates, below 1,400 pc/ph/pl for multilane highways, and about 100 pc/ph/pl for two-lane highways. Thus according to the HCM, even without a signal interrupting the flow, it is apparent that two-lane highways and interstates or multilane highways have different sensitivities to an increase in volume.

- *Urban streets are affected by signalization.* The capacities shown in Exhibit A1 for urban streets are based on an assumption of a link having 45 percent of effective green time. Although this is a reasonable assumption for a heavily signalized corridor, it is acknowledged that signal details, which are often not available at the planning stage, will heavily influence the speeds and capacities. On a related note, the v/c ratio of greater than 1.0 usually reflects problems at a particular signal. The fact that the v/c ratio has a different meaning for interrupted flow facilities, such as urban streets, than for uninterrupted flow facilities, such as interstates, suggests that the updated BPR technique in Eq. 7 is reasonable.

- *A roadway can quickly transition within HCM facility types*. Route 20, for example, can be classified as a two-lane two-way highway in the southern portion of Albemarle County (where there are very few signals) yet functions more as an urban street in the City of Charlottesville.

- *The HCM generally does not clearly distinguish between classifications such as rural, urban, principal, major, or minor*. Certainly functional classifications may help a planner choose the right facility type. Within VDOT, however, it appears that principal arterials tend to have two or more lanes (making them an urban street or a multilane highway) whereas minor arterials tend to have one lane (making them either an urban street or a two-lane highway). Thus mapping from a VDOT facility type to an HCM facility type is not always straightforward.

Comparison of the VDOT Central Office Post-processor, the Modified BPR Post-processor and the 2000 HCM

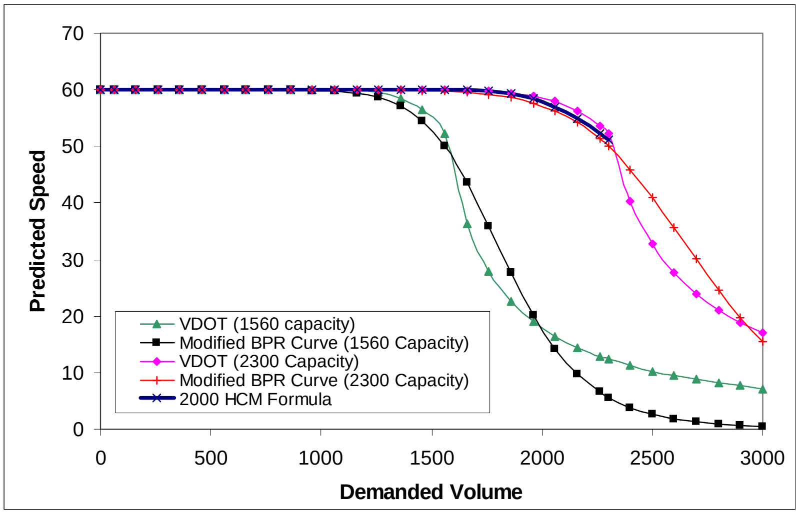
Exhibits A2 through A4 compare the predicted speeds as a function of volumes for freeways, two-lane highways, and urban (signalized) streets, with curves shown for the current VDOT post-processor (Eq. 9), the HCM, and the modified BPR approach (Eq. 7). On balance, the comparisons suggest that the formulation of the post-processor, although important, may not be as important as assumptions regarding the capacity and facility characteristics.

Freeway Segments

Exhibit A2 illustrates that although the formulation (e.g., Eq. 7 as opposed to Eq. 9) can affect the performance, it is more important to use the correct capacity of 2,300 as opposed to 1,560 if to reproduce the HCM curve. The interpretation of Exhibit A2 is that for interstate facilities (as well as multilane facilities with curves of a similar shape) it is probably a better use of resources to get the capacity correct than to pick the exact form of the v/c equation. Although they are not shown in this report, HCM curves for multilane highways are generally similar in shape to Exhibit A2, with free flow speeds maintained at low and moderate volumes followed by a sharp drop in speed at volumes near capacity.

Examination of the VDOT post-processor equations (Eqs. 9c and 9d) shows that for cases of oversaturation (e.g., *v/c* ratio > 1) the travel time is affected by the link length. (The rationale for this is that time is needed for the queue to dissipate, which is affected by the length of the link.[1]) Exhibits A2 and A4 used a link length of 1.54 miles for the purposes of the illustration.

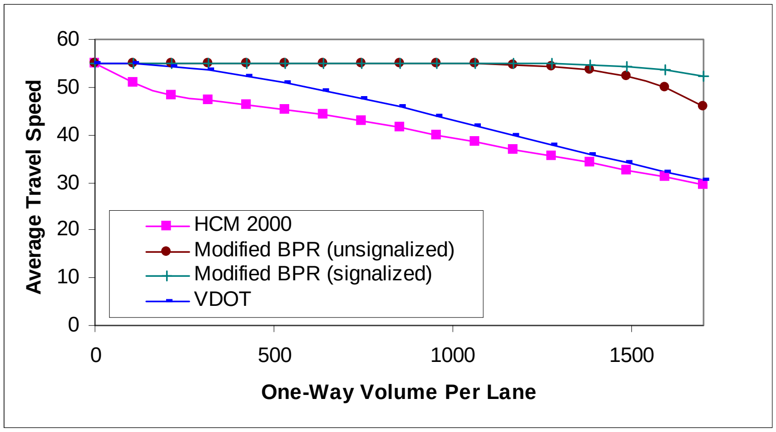
Exhibit A2. Predicted Travel Speeds for Freeways



Two-Lane Highways

Exhibit A3 shows that the VDOT post-processor replicates the HCM 2000 more closely than the either of the modified BPR equations for signalized or unsignalized facilities. The challenge with using the curves shown in Exhibit A3, however, is that two-lane highways do not correspond exclusively to only one VDOT functional classification type. It is evident that according to the HCM, speeds on two-lane highways decrease as soon as volumes begin to climb above 0; unlike freeways, even a small volume will decrease speeds.

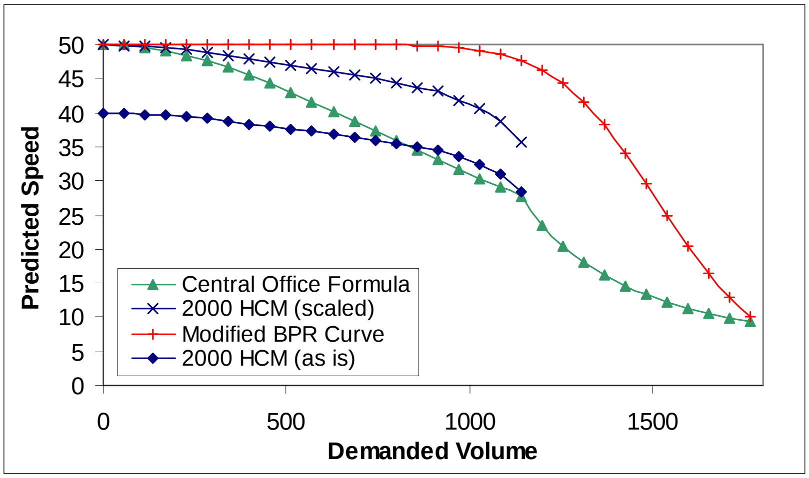
Exhibit A3. Predicted Travel Speeds for Two-Lane Highways (assumes 60% no passing zones)



Urban Streets

Exhibit A4 shows predicted speeds for urban streets, with the 2000 HCM as properly applied and then with the HCM 2000 "scaled" by a factor of 1.25, such that a free flow speed of 50 mph could be obtained. Using the HCM 2000, the Central Office post-processor may be said to be closer in terms of predicted values, although the shape of the curve suggested by the modified BPR equation mimics the shape of the HCM curve. However, the assumptions for urban streets are heavily dependent on signals: Thus the impact of default values in the estimation of travel speeds for urban streets is more severe than the impact of default values for interstates.

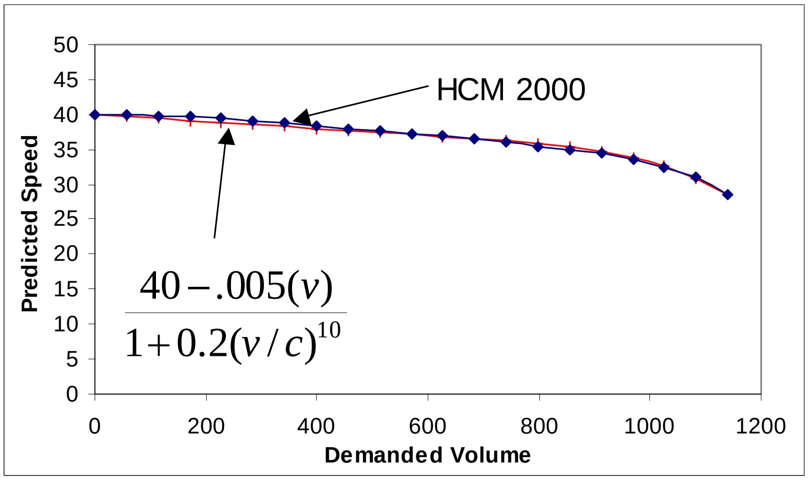
Exhibit A4. Predicted Travel Speeds for Class I Urban Street (1 signal/mi, 45% effective green time)



Synopsis of a Post-processor Based on the 2000 HCM

To build a post-processor based on the 2000 HCM, three steps are required. First, the functional classifications that are used in regional planning models (e.g., rural principal arterial) must be converted to HCM facility types. Except for interstates, this does not appear to be a task that can be automated, especially when there are four class types of urban streets. Second, the equations for freeways and two-lane highways, reflected in Exhibits A2 and A3 and given in the HCM, can easily be coded in the form of a spreadsheet, as was done for this appendix. Third, since the HCM does not give equations for urban streets but rather shows empirical data, formulations that represent these data should be developed. For example, Exhibit A5 shows that an equation can be picked to replicate the 2000 HCM data for class I urban streets.

Exhibit A5. Fitting a Curve to 2000 HCM Data for Class I Urban Streets



The material in this appendix is based on the presumption that the default values in the HCM apply to VDOT facilities—a seemingly reasonable assumption for interstate segments but not necessarily for urban streets, owing to the fact that signal density and progression will heavily influence travel time on those facilities. Missing from Exhibits A2 through A6 is a curve that shows "measured data on VDOT facilities," a curve that would show wide variation in Exhibits A4 and A5. Thus a caveat to using the 2000 HCM is the same caveat that applies to the other three post-processors: in the absence of a validation effort, it is difficult to pick one post-processor over the other. Thus the investigators believe that although an HCM-based post-processor may indeed prove to be the most appropriate for VDOT, such a decision should be based on a comparison of actual and measured results. Thus in the short term, VDOT staff should pick one or more post-processors just to get started and over the coming year collect data on selected facilities.