
Procedures for Developing MOVES-Based Paved Roads Particulate Matter Emissions Inventories

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**PROCEDURES FOR DEVELOPING MOVES-BASED PAVED ROADS
PARTICULATE MATTER EMISSIONS INVENTORIES FOR
CONFORMITY ANALYSIS**

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TEXAS A&M TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843

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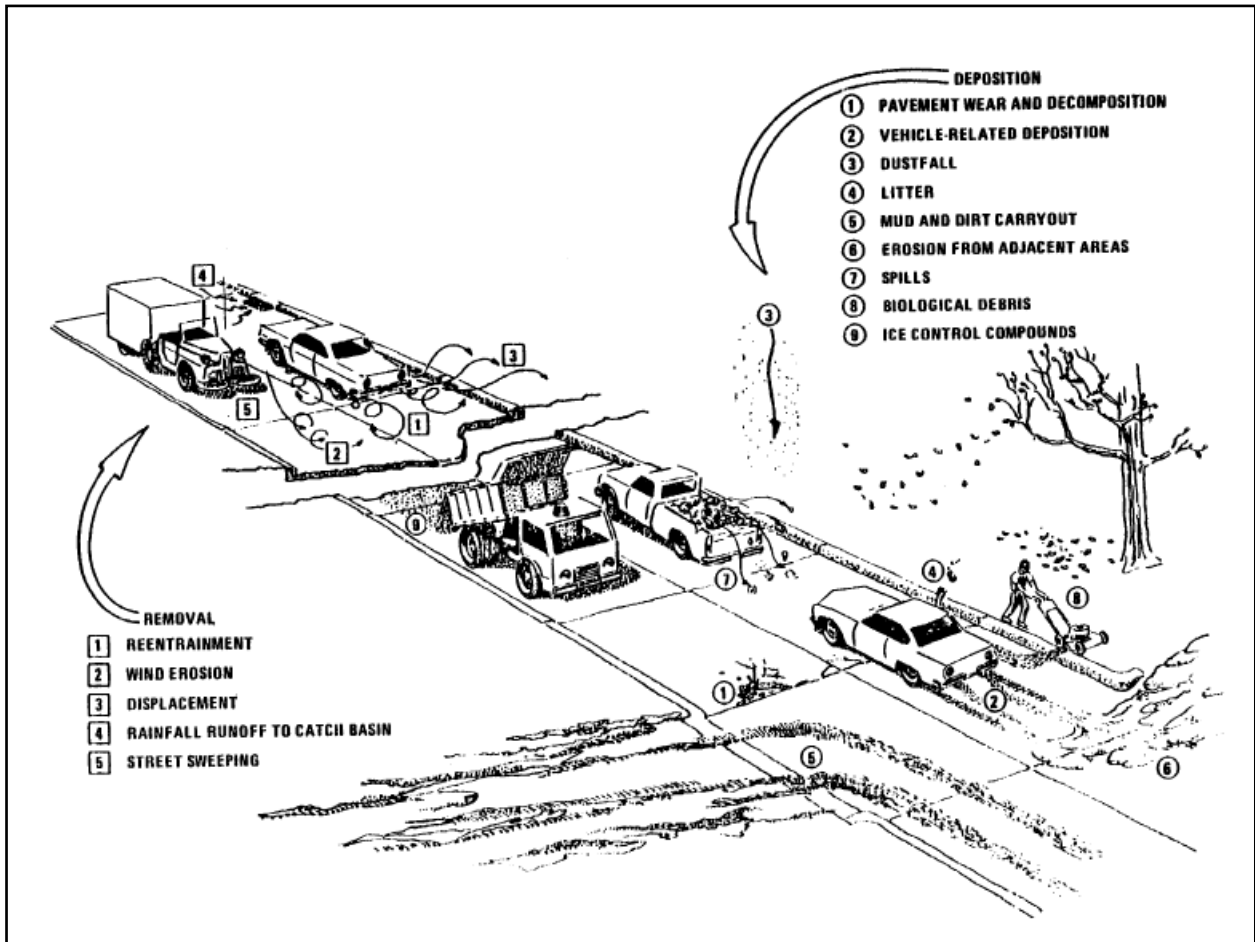
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INTRODUCTION

Particulate matter (PM) is a general term referring to solid or liquid particles found in the air. PM can be classified into multiple categories based on the size of the particles, with the main focus being on PM_{2.5} (particulate matter with an aerodynamic diameter equal to or less than 2.5 micrometers) and PM₁₀ (particulate matter with an aerodynamic diameter equal to or less than 10 micrometers). PM emissions for paved roads are produced by two main sources: direct vehicle emissions and re-suspended emissions. The direct vehicle PM emissions are produced from the travel of the actual vehicles themselves. The re-suspended emissions are the result of the loose material on the roadway. For a conformity analysis, both sources are typically included in the PM emissions estimates.

Direct vehicle emissions are comprised of exhaust, brake wear, and tire wear PM emissions. Emissions factors for the direct vehicle emissions are included with the U.S. Environment Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES). The latest version of this emissions factor model, MOVES2010b, has the capability of estimating the exhaust, brake wear, and tire wear emissions factors for both PM_{2.5} and PM₁₀. These emissions factors, along with link-level vehicle miles traveled (VMT) and speed estimates, are used to calculate the direct vehicle emissions using the Texas A&M Transportation Institute's (TTI) emissions inventory development procedures.

The re-suspended emissions are essentially due to loose material on the road surface. While being depleted by some sources (e.g., wind, displacement, and rainfall), loose material is constantly being replenished by other sources, such as pavement wear and decomposition, deposits from vehicles, and biological debris (see Figure 1). The EPA has developed an equation for calculating daily re-suspended emissions factors. These emissions factors, along with the VMT from the direct vehicle emissions calculations, are used to estimate the daily re-suspended PM emissions. For a conformity analysis, these re-suspended paved road PM emissions are added to the direct vehicle paved road emissions to estimate the total paved road PM emissions.



Source: EPA, AP-42, Section 13.2.1.2, Figure 13.2.1-1, January 2011.

Figure 1. Deposition and Removal Process of Loose Material on Paved Roads.

DIRECT VEHICLE EMISSIONS

The direct vehicle emissions consist of the exhaust, brake wear, and tire wear PM emissions, which are included in MOVES2010b for PM_{2.5} and PM₁₀. TTI has developed an inventory method that is a detailed, hourly, MOVES rates-per-activity-based method. This method produces hourly emissions estimates by MOVES source use type (SUT)/fuel type (Table 1), pollutant and emissions process (Table 2).

Table 1. MOVES SUT/Fuel Types.

SUT ID	SUT Description	SUT Abbreviation ¹
11	Motorcycle	MC
21	Passenger Car	PC
31	Passenger Truck	PT
32	Light Commercial Truck	LCT
41	Intercity Bus	IBus
42	Transit Bus	TBus
43	School Bus	SBus
51	Refuse Truck	RT
52	Single Unit Short-Haul Truck	SUShT
53	Single Unit Long-Haul Truck	SULhT
54	Motor Home	MH
61	Combination Short-Haul Truck	CShT
62	Combination Long-Haul Truck	CLhT

¹ The SUT/fuel type labels are the combined SUT abbreviation and fuel type names separated by an underscore (e.g., MC_Gas, RT_Diesel, and SBus_Gas are motorcycles, diesel-powered refuse trucks, and gasoline-powered school buses).

Table 2. MOVES Model Emissions Processes.

Process ID	Process Name
1	Running Exhaust
2	Start Exhaust
9	Brake Wear
10	Tire Wear
11	Evaporative Permeation
12	Evaporative Fuel Vapor Venting
13	Evaporative Fuel Leaks
15	Crankcase Running Exhaust
16	Crankcase Start Exhaust
17	Crankcase Extended Idle Exhaust
90	Extended Idle Exhaust

This method uses the MOVES emissions and activity output to develop roadway-based emissions factors, as well as off-network emissions factors in terms of grams per source hour parked (SHP), grams per start, and grams per extended idle hour (SHI) based on the emissions process. Table 3 shows the emissions rates by process and activity measure.

Table 3. Emissions Rates by Process and Activity Measure.

Emission Processes	Activity¹	Emissions Factor Units
Running Exhaust Crankcase Running Exhaust Brake Wear Tire Wear	VMT	grams/mile (g/mi)
Evaporative Permeation Evaporative Fuel Vapor Venting Evaporative Fuel Leaks	VMT	g/mi
	SHP	g/shp
Start Exhaust Crankcase Start Exhaust	starts	g/start
Extended Idle Exhaust Crankcase Extended Idle Exhaust	SHI	g/shi

¹ The amount of travel on roads (VMT), SHP, vehicle starts, and SHI are the basic activity factors. SHI is for Combination Long-Haul Trucks only. Evaporative permeation, fuel vapor venting, and fuel leaks occur both during operation and while parked.

To calculate emissions using this method, the SUT/fuel type VMT mix, link-based VMT and speeds (either travel model or virtual link-based) and off-network activity (SHP, starts, and SHI) are used with the emissions rates to calculate the emissions. For the roadway-based emissions, the SUT/fuel type VMT mix is applied to the link VMT and speeds to calculate the link VMT by SUT/fuel type and multiplied by the appropriate roadway-based emissions factor. For the off-network emissions, the off-network emissions rates are multiplied by the appropriate off-network activity based on the emissions process (see Table 3). TTI has developed a set of computer utilities to calculate and summarize detailed on-road mobile source emissions inventories using this method, which are described in more detail in Appendix A (more information can also be found in *TTI Emissions Inventory Estimation Utilities Using MOVES: MOVES2010bUtl User's Guide*, TTI). Since the exhaust, brake wear, and tire wear emissions processes are all considered roadway-based (see Table 3), only the major components related to the roadway-based emissions calculations (SUT/fuel type VMT mix, hourly link-based VMT and speeds, emission rates, and emissions calculations) are discussed in the following.

VMT Mix

The VMT mix is a major component of the link-based emissions estimation process. The VMT mix is an estimate of the fraction of on-road VMT attributable to each SUT by fuel type and is used to subdivide the hourly link VMT estimates into hourly link VMT by SUT/fuel type, which is combined with the appropriate emissions factors to calculate the link emissions. The VMT mix is also used to designate the SUT/fuel types that are to be included in the emissions inventory

The SUT/fuel type VMT mixes are calculated by MOVES road type (additional road types may be included but are optional) using TTI's SUT/fuel type mix method (*Methodologies for Conversion of Data Sets for MOVES Model Compatibility*, TTI, August 2009). Link road type designations are used to associate the link road types to the VMT mix road types. The current VMT mix method produces 24-hour average and time period (AM Peak, Mid-Day, PM Peak, and Overnight) VMT mixes by road type for each of the 25 TxDOT districts, four day types (Weekday, Friday, Saturday, and Sunday), and VMT mix year (five year increments beginning with 2005). The main data sources used to develop the VMT mixes are recent, multi-year Texas Department of Transportation (TxDOT) vehicle classification counts, year-end TxDOT/Texas Department of Motor Vehicle (TxDMV) registration data, along with MOVES default data where needed.

Hourly Link-Based VMT and Speeds

The activity required to calculate the roadway-based emissions is the hourly link-based VMT and speeds. For those counties where a travel demand model (TDM) is available, the hourly link-based VMT and speeds are based on the TDM. VMT factors, hourly factors, and directional split factors are used to estimate the link-level VMT by hour and direction for the emissions inventory season by day type (i.e., summer weekday). For those counties where a TDM is not available, TTI uses a virtual link method to estimate the hourly link-based VMT and speeds. This method uses the HPMS functional class/area type combinations to create a virtual network. VMT factors, hourly factors, and directional split factors are used to estimate the link-level VMT by hour and direction for the emissions inventory season by day type (i.e., summer weekday).

TDM-Based Hourly Link VMT and Speeds

For those counties where a TDM is available, the TDM-based method is used to develop the hourly link-based VMT and speeds. VMT factors are applied to the link-level TDM VMT to calculate the inventory season and day type link-level VMT. Hourly factors are used to distribute the inventory season and day type link-level VMT to each hour. Directional split factors are used to split the hourly inventory season and day type link-level VMT by direction. A speed model is applied to the hourly inventory season and day type link-level VMT by direction to estimate the operational speeds. TTI has developed an electronic utility to develop the TDM-based hourly link VMT and speeds (TRANSVMT). A more detailed description of this utility and the calculation process is included under the TRANSVMT section of Appendix A.

The TDM is the basis for developing the hourly link-based VMT and speeds using the TDM –based method. The TDM typically spans multiple counties and has various attributes (i.e., functional class, area type, coded speeds) that vary by TDM. Intrazonal VMT are not included in the TDM and are estimated using the TDM’s trip matrix and the intrazonal radii. The TDM can be either a 24-hour TDM or a four-time period TDM (depending upon the area). However, the main procedure for developing the hourly link-based VMT and speeds remains the same.

VMT factors are used to calculate the inventory season and day type link-level VMT. The type of VMT factors that are used depends on the year of the emissions inventory and TDM. For historical years (i.e., any year where TxDOT’s Roadway Inventory Functional Classification Record [RIFCREC] reports are available), county-level VMT control totals (based on seasonal day type VMT adjustment factors and county-level RIFCREC data for the year of the emissions inventory) are used to calculate the county-level VMT factors. These county-level VMT factors are calculated by dividing the county-level VMT control total by the county-level VMT from the TDM (including the estimated intrazonal VMT).

For future years, a Highway Performance Monitoring System (HPMS) adjustment factor and a seasonal adjustment factor are used for the VMT factors. The HPMS adjustment factor is calculated using the area’s validation year TDM by converting the area’s HPMS annual average daily traffic (AADT) VMT to annual non-summer weekday (ANSWT) and dividing by the total TDM VMT (including the intrazonal VMT). The seasonal adjustment factor is used to convert

the TDM ANSWT VMT to the inventory season and day type VMT. This factor is developed using multi-year aggregated automatic traffic recorder (ATR) data by dividing the average seasonal day-of-week count by the ANSWT traffic count. All VMT factors are applied to each link in the TDM and the estimated intrazonal VMT.

Virtual Link-Based Hourly Link VMT and Speeds

For those counties where a TDM is not available, the virtual link method is used to develop the hourly link-based VMT and speeds. The virtual link method is based on AADT VMT estimates and the HPMS functional class/area type combinations, which are used to create a virtual network of up to 42 virtual links (a 21-cell array of seven roadway categories by three area types split by direction). A seasonal day-type VMT adjustment factor is applied to the county-level AADT VMT to develop a county-level VMT control total representative of the inventory season and day type. The VMT control total is disaggregated to the virtual using data from TxDOT's RIFCREC reports. Hourly travel factors and directional split factors are applied to the virtual links to calculate the hourly link VMT by direction. Link-level hourly operational speeds are estimated using a speed model based on delay, volume, capacity and free-flow speed. TTI has developed an electronic utility to develop the virtual link-based hourly link VMT and speeds (VirtualLinkVMT). A more detailed description of this utility and the calculation process is included under the VirtualLinkVMT section of Appendix A.

For historical years (i.e., any year where TxDOT's RIFCREC reports are available), the county-level AADT VMT estimates are taken directly from the TxDOT RIFCREC data for the inventory year. For future years, the AADT VMT estimates are the average of two forecasts: one from a linear regression of historical county HPMS data (from the RIFCREC reports) and one using VMT per capita estimates with the latest Texas State Data Center (TSDC) county population projections.

A seasonal day-type VMT factor is applied to the county-level AADT VMT to calculate the VMT control total, which represents the VMT for the emissions inventory season and day type. This factor is developed using multiple years of TxDOT ATR vehicle count data, which are aggregated to produce factors by TxDOT district. The seasonal day-type VMT factor is calculated as the ratio of the seasonal, day type volume to the AADT volume.

The RIFCREC data is used to disaggregate the VMT control to each of the 21 roadway/area type categories listed in the RICREC data. For historical years, the RIFCREC data for the inventory year is used. For future years, the most recent available RIFCREC data is used. The control total VMT disaggregation is performed in two steps. First, the county VMT control total is divided by the county AADT VMT from the RIFCREC data. This ratio is then multiplied by the corresponding AADT VMT by functional class/area type (in essence, a scaling of link VMT from the RIFCREC data to the inventory season and day type).

Hourly travel factors are used to allocate the 24-hour seasonal, day-type specific VMT to each hour. These factors are developed at the TxDOT district level using multi-year TxDOT ATR data and calculated as the ratio of the inventory season and day type hourly volume to the inventory season and day type 24-hour volume.

Directional split factors are used to allocate the hourly VMT by direction to allow for differences in congestion levels based on the direction of traffic flow; thus, breaking the 21-cell array of VMT by functional class/area type into the 42 virtual links. A 60/40 directional split ratio is applied based on aggregate observed values.

TTI uses a speed model based on delay, volume, capacity, and free-flow speed to calculate the link's hourly operational speed. The hourly directional VMT estimates for each link are divided by the link's centerline miles (from the RIFCREC data) to produce the link volume estimates required by the speed model. Link-level hourly operational speed is calculated by estimating delay (as a function of volume-to-capacity $[v/c]$) on each link and applying it to the link's free-flow speed.

Emissions Rates

MOVES2010b produces emissions rates for two categories — VMT-based and population based. However, TTI has developed a procedure for calculating the emissions rates in terms of rates-per-activity, which includes VMT-based emissions rates and off-network emissions rates (related to SHP, starts, and SHI). This procedure uses the MOVES emissions output and the MOVES activity output to calculate the emissions rates. For the VMT-based emissions rates (PM emissions are considered VMT-based only), the procedure extracts the VMT-based emissions from the MOVES output (which are by pollutant, process, road type, hour, and average speed bin) and divides these emissions by the appropriate VMT from the MOVES activity output.

Thus producing emissions rates by pollutant (PM_{2.5}, PM₁₀), process (exhaust, brake wear, tire wear), road type, hour, and average speed bin (i.e., 2.5, 5, 10, ..., 75 mph). TTI has developed an electronic utility for calculating the MOVES-based emissions rates (MOVESratesCalc). A more detailed description of this utility and the calculation process is included under the MOVESratesCalc section of Appendix A.

For most cases, county-level MOVES runs are required to calculate the emissions rates. Local data is used in these MOVES runs when possible (i.e., age distributions, fuel engine fractions, fuel parameters, meteorology data). For other types of analyses, MOVES runs based on county groupings may be used. Although local data is still used in these MOVES runs, the local data that is used is typically indicative of the county group rather than county-specific data.

Emissions Calculations

For the VMT-based emissions, the VMT mix, link VMT and speeds, and the VMT-based emissions rates are used to calculate the emissions. The first step in the emissions calculation process is the SUT/fuel type VMT calculation. The VMT mix is applied to the link VMT to distribute the VMT to each SUT/fuel type category using an emissions rate road type to link road type/area type designation that associates the link to one of the VMT mix road types.

The second step is the calculation of the emission rates by SUT/fuel type for the link speed. Emissions rates for the link speed are calculated using the rates road type to link road type/area type designation to determine the appropriate emissions rate road type, the link speed, and the emissions rates by average speed bin. For link speeds below 2.5 mph, the rates for 2.5 mph are used. For link speeds greater than 75 mph, the rates for 75 mph are used. Otherwise, the emissions rates are interpolated using the link speed and the emissions rates for the speed bins (i.e., 2.5, 5, 10, ..., 75 mph) bounding the link speed.

The third step is the actual emissions calculations. To calculate the link level emissions, the SUT/fuel type VMT is multiplied by the SUT/fuel type emissions rates. This process is repeated for each link within a given hour and for each hour of the day. The link emissions for each hour are aggregated to produce the hourly, county-level emissions. TTI has developed an electronic utility to perform the link-level emissions calculations (MOVESemscalc). Appendix A contains a more detailed description of this utility and the emissions calculation process.

RE-SUSPENDED EMISSIONS FOR PAVED ROADS

The re-suspended emissions for paved roads are due to loose material on the road surface, which are not included in the MOVES emissions factor model. The EPA has developed a set of equations for calculating emission factors (AP-42, Section 13.2.1). Although this section of AP-42 contains multiple equations for estimating these emissions factors, TTI has focused on the daily equation with a precipitation correction term (AP-42, Section 13.2.1, Equation 2):

$$E_{\text{ext}} = [k (\text{sL})^{0.91} \times (\text{W})^{1.02}] (1 - \text{P}/4\text{N})$$

Where,

- E_{ext} = emission factor (same units as k);
- K = particle size multiplier;
- sL = road surface silt loading (grams per square meter, g/m^2);
- W = average weight (tons) of the vehicles traveling the road;
- P = number of “wet” days with at least 0.254 mm (0.01 in) of precipitation during the averaging period (N); and
- N = number of days in the averaging period.

The first component of the emission factor equation is the particle size multiplier (k). The particle size multiplier varies with aerodynamic size range (i.e., $\text{PM}_{2.5}$, PM_{10} , etc.). Table 4 shows the various particle size multipliers.

Table 4. Particle Size Multiplier (k) for Paved Road Emission Factor Equation.

Size Range ¹	Particle Size Multiplier (k)		
	g/VKT	g/VMT	Lb/VMT
$\text{PM}_{2.5}$	0.15	0.25	0.00054
PM_{10}	0.62	1.00	0.0022
PM_{15}	0.77	1.23	0.0027
PM_{30}	3.23	5.24	0.011

¹ Taken from AP-42, Section 13.2.1, Table 13.2.1-1.

² Units are grams per vehicle kilometer (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT).

The second component of the emissions factor equation is the road surface silt loading (sL), which is the mass of silt-size material (equal to or less than 75 micrometers in diameter) per unit area of the roadway. Silt loading is the product of the silt fraction (proportion of loose dry surface dust that passes through a 200-mesh screen) and the total loading (loose material

collected by broom sweeping and vacuuming of the paved roadway). More information regarding the silt loading can be found in AP-42, Section 13.2.1.2. This is a critical parameter in estimating the paved road re-suspended PM emissions factors; thus using silt loading values specific to the analysis area (or as closely related as possible) is highly recommended.

TTI uses the silt loading values used in setting the PM emissions budget, unless more recent values are available. Since any type of control techniques (i.e., street sweeping) affect the silt loading directly, TTI does not account for any control measures when estimating the PM emissions unless controlled silt loading values are available. If appropriate silt loading values are not available, default silt loading values may be used. Table 5 shows the default values for normal baseline conditions and wintertime baseline conditions (only for areas that experience frozen precipitation and periodic application of antiskid material) (more information on the use of these default values can be found in AP-42, Section 13.2.1.3).

Table 5. Default Silt Loading Values (g/m²).

Condition ¹	ADT Category			
	< 500	500 – 5,000	5,000 – 10,000	> 10,000
Ubiquitous Baseline	0.6	0.2	0.06	0.03 0.015 limited access
Ubiquitous Winter Baseline Multiplier during months with frozen precipitation ²	X4	X3	X2	X1
Initial peak additive contribution from application of antiskid abrasive (g/m ²)	2	2	2	2
Days to return to baseline conditions (assume linear decay)	7	3	1	0.5

¹ Taken from AP-42, Section 13.2.1, Table 13.2.1-2.

² Shown as a multiple of Ubiquitous baseline (ie., for ADT < 500: 0.6 X 4 = 2.4 g/m²).

The third component of the emissions factor equation is the average weight (tons) of the vehicles traveling the road (W). This is another critical parameter when calculating the re-suspended PM emissions factors (the higher the average weight of vehicles traveling the road, the higher the PM emissions factor). Since the emissions factor equation uses the average weight of all vehicles traveling the road, the equation is not intended to be used to calculate an emissions factor for each vehicle type but rather an emissions factor for the entire fleet. TTI has developed a procedure for calculating the average vehicle weight using the vehicle type VMT (same VMT used to calculate the direct vehicle emissions) to essentially create a two-hour mix by vehicle type and a set of vehicle type-specific vehicle weights (described in more detail in the following re-suspended emissions calculations section).

The final component of the emissions factor equation is the precipitation data, which consist of the number of “wet” days with at least 0.254 mm (0.01 in) of precipitation during the averaging period (P) and the number of days in the averaging period (N). Given the effect of precipitation on the PM emissions (i.e., more precipitation means less loose material on the roadway), the precipitation is another critical parameter when estimating the re-suspended PM emissions factors. These precipitation data are specific to each area and vary by season. This data can come from a variety of sources, such as the National Climatic Data Center (NCDC) and the National Weather Service (NWS).

Emissions Factor and Emissions Calculations

TTI has developed a spreadsheet application that calculates re-suspended PM emissions factors and emissions for four road type categories (freeway, arterial, collector and local) using the paved roads equation listed previously (AP-42, Section 13.2.1, Equation 2). This spreadsheet has the capability of estimating the emissions factors and emissions for either summer or winter and for any of the main PM categories ($PM_{2.5}$, PM_{10} , PM_{15} , or PM_{30}). A number of user-supplied inputs are required by the utility. These inputs include:

- The tab-delimited VMT and emissions output from the direct vehicle calculations (output from MOVESemscal utility or similar format);
- County name as it appears in the tab-delimited VMT and emissions output;
- Analysis year;
- Season (summer or winter);

- The output units for the emissions (grams, pounds, or tons);
- The PM category (PM_{2.5}, PM₁₀, PM₁₅, or PM₃₀);
- The road surface silt loading (sL) for each road type category (freeway, arterial, collector and local);
- The precipitation data (number of wet days with ≥ 0.01 inches of rain and the number of days in the period) for the specified season; and
- A table listing each road type in the VMT and emissions output and corresponding road type category.

The user-supplied inputs are located in two sheets in the spreadsheet, the “Notes” sheet and the “Inputs” sheet. Figure 2 and Figure 3 show a sample of these inputs.

Inputs	
County =	El Paso 141
Year =	2011
Season =	Summer
Output Units =	Pounds
PM Type =	PM-10
Files	
MOVESemscal Tab Output -	C:\ReSusp_Dust_AP42\MOVES_TabIn\ELP_48141_ems_2011sumWkd.TAB

Figure 2. Sample User-Supplied Inputs from “Notes” Sheet.

Road Surface Silt Loading (sL)		Precipitation Data		
Road Type	sL(g/m ²)	Season	Number of wet days (>= 0.01" of rain)	Number of days in the period
Freeway	0.003278	Summer	77	368
Arterial	0.062	Winter	26	361
Collector	0.115			
Local	0.21009			
MOVESemscalc Tab Output Road Types				
ROADWAY TYPE	Roadway Category			
Centroid Connector	Local			
Border Highway	Arterial			
Radial Freeway	Freeway			
Expressways	Arterial			
Divided Principal Arterials	Arterial			
Undivided Principal Arterials	Arterial			
Divided Minor Arterial	Arterial			
Undivided Minor Arterial	Arterial			
Divided Collector	Collector			
Undivided Collector	Collector			
Local	Local			
Frontage Road	Arterial			
Ramp	Arterial			
Transmountain Highway	Arterial			
Circumferential Freeway	Freeway			
Intrazonal	Local			

Figure 3. Sample User-Supplied Inputs from “Notes” Sheet.

Two sets of constants are also included in the spreadsheet — average vehicle weight by SUT/fuel type and the particulate size multipliers (k) by PM category. The average vehicle weights have been set by TTI and should not be changed unless other data becomes available that would require an update to these average vehicle weights. The particulate size multipliers are taken directly from AP-42. Figure 4 shows the constants.

Average Vehicle Weight		Particulate Size Multiplier (k)	
Vehicle Type	Ave. Weight (lbs)	PM Type	k (g/VMT)
MC_Gas	700.0	PM-2.5	0.25
PC_Gas	3,000.0	PM-10	1
PC_Diesel	3,000.0	PM-15	1.23
PT_Gas	6,000.0	PM-30	5.24
PT_Diesel	6,000.0		
LCT_Gas	16,000.0		
LCT_Diesel	16,000.0		
IBus_Diesel	33,000.0		
TBus_Gas	33,000.0		
TBus_Diesel	33,000.0		
SBus_Gas	26,000.0		
SBus_Diesel	26,000.0		
RT_Gas	33,000.0		
RT_Diesel	33,000.0		
SUShT_Gas	33,000.0		
SUShT_Diesel	33,000.0		
SULhT_Gas	33,000.0		
SULhT_Diesel	33,000.0		
MH_Gas	33,000.0		
MH_Diesel	33,000.0		
CShT_Gas	60,000.0		
CShT_Diesel	60,000.0		
CLhT_Gas	60,000.0		
CLhT_Diesel	60,000.0		

Figure 4. Sample Constants.

The first step in the calculation process is the VMT summary by roadway category and SUT/fuel type. The spreadsheet imports only the 24-hour VMT from the tab-delimited VMT and emissions file, which is by road type and SUT/fuel type. Using the 24-hour VMT and the user-supplied road type/roadway category correlations (see Figure 3), the spreadsheet assigns each road type a roadway category and creates a summary of the VMT by SUT/fuel type. Figure 5 shows a sample of the VMT summary by roadway category and SUT/fuel type (only a sample of the SUT/fuel type VMT is shown but the spreadsheet includes all of the vehicle types listed in Figure 4).

ROADWAY TYPE	Roadway Category	MC_Gas	PC_Gas	PC_Diesel	PT_Gas	PT_Diesel	LCT_Gas	LCT_Diesel	....	TOTALS
Centroid Connector	Local	1036.254665	1038109.244	1036.254665	205508.4183	6134.554202	65891.98742	4655.407639	....	1421624.595
Border Highway	Arterial	241.2271486	240918.3779	241.2271486	36804.83015	1099.995798	11800.83211	833.0377532	....	321636.1982
Radial Freeway	Freeway	3431.168171	3425685.382	3428.933648	529396.3077	15821.31344	169740.4717	11982.59188	....	4619581.349
Expressways	Arterial	88.34650435	88233.42082	88.34650435	13479.32066	402.8600598	4321.910993	305.0899283	....	117795.3391
Divided Principal Arterials	Arterial	3265.599439	3271412.318	3265.599439	648656.8201	19362.87923	207978.2652	14694.11058	....	4482485.094
Undivided Principal Arterials	Arterial	873.4854851	874730.7752	873.4854851	183591.6817	5481.025534	58864.71079	4158.999077	....	1223025.137
Divided Minor Arterial	Arterial	322.9460407	323608.3551	322.9460407	61297.44313	1829.581284	19653.78154	1388.558943	....	436493.9089
Undivided Minor Arterial	Arterial	862.8820857	864528.6729	862.8820857	167791.6502	5008.460156	53798.93502	3800.981222	....	1175830.762
Divided Collector	Collector	14.82238187	14852.82784	14.82238187	2811.845901	83.92672978	901.5613622	63.69618155	....	20030.24577
Undivided Collector	Collector	387.156082	387639.4928	387.156082	83607.38887	2496.193455	26806.87808	1894.017269	....	547407.3599
Local	Local	0	0	0	0	0	0	0	....	0
Frontage Road	Arterial	446.876159	447786.41	446.876159	85023.15679	2537.751097	27260.94757	1926.01439	....	604481.4925
Ramp	Arterial	298.5670682	298181.0301	298.5591365	45574.28549	1362.087675	14612.60166	1031.525923	....	398248.0579
Transmountain Highway	Arterial	62.29905237	62053.85409	62.29905237	23980.11379	716.6060511	7688.574949	543.3074788	....	113176.0152
Circumferential Freeway	Freeway	353.4991507	351837.1214	351.0215791	60466.90901	1806.19774	19386.23093	1368.909182	....	520883.6328
Intrazonal	Local	35.91576765	35989.54058	35.91576765	6813.318193	203.3609006	2184.5523	154.3407313	....	48534.82115

Figure 5. VMT Summary by Road Type and SUT/Fuel Type.

The next calculation step is the average vehicle weight calculations. Using the vehicle type average vehicle weights (see Figure 4) and the VMT by roadway category and vehicle type (see Figure 5), the average vehicle weights are multiplied by the vehicle type VMT and is divided by the total roadway category VMT to calculate the roadway category average vehicle weight; thus creating a VMT weighted average vehicle weight. This calculation is performed for each roadway category (freeway, arterial, collector, and local). Figure 6 shows a sample of the average vehicle weight calculations.

Vehicle Type	Ave. Weight (lbs)	Freeway		Arterial		Collector		Local	
		VMT	VMT Weighted Vehicle Weight (lbs)	VMT	VMT Weighted Vehicle Weight (lbs)	VMT	VMT Weighted Vehicle Weight (lbs)	VMT	VMT Weighted Vehicle Weight (lbs)
MC_Gas	700.0	3,784.7	0.52	6,462.2	0.51	402.0	0.50	1,072.2	0.51
PC_Gas	3,000.0	3,777,522.5	2,204.58	6,471,453.2	2,187.98	402,492.3	2,127.95	1,074,098.8	2,191.80
PC_Diesel	3,000.0	3,780.0	2.21	6,462.2	2.18	402.0	2.13	1,072.2	2.19
PT_Gas	6,000.0	589,863.2	688.49	1,266,199.3	856.20	86,419.2	913.78	212,321.7	866.53
PT_Diesel	6,000.0	17,627.5	20.58	37,801.2	25.56	2,580.1	27.28	6,337.9	25.87
LCT_Gas	16,000.0	189,126.7	588.67	405,980.6	732.06	27,708.4	781.29	68,076.5	740.89
LCT_Diesel	16,000.0	13,351.5	41.56	28,681.6	51.72	1,957.7	55.20	4,809.7	52.35
IBus_Diesel	33,000.0	4,320.6	27.74	16,603.7	61.75	1,172.8	68.21	2,895.9	65.00
TBus_Gas	33,000.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
TBus_Diesel	33,000.0	1,332.7	8.56	5,185.2	19.28	366.5	21.31	904.9	20.31
SBus_Gas	26,000.0	56.1	0.28	174.7	0.51	12.2	0.56	30.2	0.53
SBus_Diesel	26,000.0	4,820.9	24.38	18,503.0	54.22	1,306.6	59.87	3,227.2	57.07
RT_Gas	33,000.0	897.4	5.76	1,592.6	5.92	109.9	6.39	261.7	5.88
RT_Diesel	33,000.0	1,579.8	10.14	2,882.6	10.72	198.3	11.53	475.4	10.67
SUSHT_Gas	33,000.0	48,344.4	310.35	87,494.9	325.40	6,024.6	350.37	14,416.6	323.60
SUSHT_Diesel	33,000.0	85,933.6	551.66	155,515.9	578.38	10,708.3	622.75	25,624.3	575.18
SULHT_Gas	33,000.0	3,744.0	24.04	6,797.3	25.28	468.0	27.22	1,120.5	25.15
SULHT_Diesel	33,000.0	6,646.6	42.67	12,102.0	45.01	833.6	48.48	1,995.5	44.79
MH_Gas	33,000.0	2,631.5	16.89	4,752.6	17.68	327.0	19.02	782.9	17.57
MH_Diesel	33,000.0	4,641.4	29.80	8,390.0	31.20	577.9	33.61	1,382.2	31.03
CShT_Gas	60,000.0	31,111.8	363.14	27,014.3	182.67	1,911.9	202.16	4,031.0	164.51
CShT_Diesel	60,000.0	118,419.6	1,382.21	102,752.0	694.80	7,273.8	769.12	15,329.3	625.62
CLhT_Gas	60,000.0	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
CLhT_Diesel	60,000.0	230,928.5	2,695.42	200,370.8	1,354.90	14,184.4	1,499.83	29,892.7	1,219.98
Total		5,140,465.0	9,039.63	8,873,172.0	7,263.94	567,437.6	7,648.56	1,470,159.4	7,067.02

Figure 6. Sample Average Vehicle Weight Calculations.

The final step in the calculation process is the calculation of the emissions factors and emissions by roadway category. Using the particulate size multiplier (Figure 4), the user-supplied silt loading values by roadway category (Figure 3), the average vehicle weight values by roadway category (Figure 6) converted to tons, and the precipitation data (Figure 3), the spreadsheet calculates the emissions factors by roadway category using the equation listed previously from AP-42, Section 13.2.1. These emissions factors are then multiplied by the total VMT by roadway category to estimate the PM emissions for the user-specified PM specification. These emissions can then be added to the direct vehicle PM emissions to obtain the total PM emissions. Figure 7 shows a sample of the emissions factor and emissions calculations.

Emission Factor Calculation						
NOTE: Emission factors based on "Emission Factor Documentation for AP-42", Section 13.2.1, Paved Roads, January 2011						
Equation	$E = [(k (sL)^{0.91} * (W)^{1.02}) * (1 - (P / (4N)))]$					
Data	Variable	Units				
Particulate Size Multiplier	k	g/VMT				
Road Surface Silt Loading	sL	g/m ²				
Average Vehicle Weight	W	tons				
Number of wet days (>= 0.01" of rain)	P	days				
Number of days in the period	N	days				
Resuspended PM-10 Emission Factors - El Paso 141, Summer 2011						
Road Type	k	sL	W	P	N	Emission Factor (g/VMT)
Freeway	1	0.00328	4.51982	77	368	0.02422
Arterial		0.06200	3.63197			0.28125
Collector		0.11500	3.82428			0.52012
Local		0.21009	3.53351			0.83028
Resuspended PM-10 Emissions - El Paso 141, Summer 2011						
Road Type	VMT	Emission Factor (g/VMT)	Emissions (g)	Emissions (Pounds)		
Freeway	5,140,464.98	0.02422	124,479.05	274.43		
Arterial	8,873,172.00	0.28125	2,495,552.38	5,501.75		
Collector	567,437.61	0.52012	295,134.52	650.66		
Local	1,470,159.42	0.83028	1,220,648.04	2,691.07		
Total	16,051,234.01	N/A	4,135,813.99	9,117.91		

Figure 7. Sample Emissions Factor and Emissions Calculations.

Control Measures

With respect to PM, the purpose of any control measure is to either prevent material from being deposited on the roadway or to remove loose material from the roadway (i.e., street sweeping or water flushing). These types of control measures affect the silt loading, which is a direct component of the emissions factor equation. To measure the effectiveness of any control measure, controlled emissions factors would have to be developed using local silt loading values after the application of the control. Since these values are typically not available, TTI does not include any control measures when estimating the re-suspended PM emissions.

**APPENDIX A:
EMISSIONS ESTIMATION UTILITIES FOR MOVES-BASED EMISSIONS
INVENTORIES**

TTI EMISSIONS ESTIMATION UTILITIES FOR MOVES BASED EMISSIONS INVENTORIES

The following is a summary of utilities developed by TTI (written in the Visual Basic programming language) for producing detailed, link-based, hourly, and 24-hour emissions estimates for on-road mobile sources using the latest version of EPA's MOVES model. These utilities produce inputs used with the MOVES model, make special adjustments to the emissions factors (when required), and multiply them with travel model link-based or HPMS-based (virtual link) activity estimates to produce emissions at user-specified temporal and spatial scales.

The main utilities for calculating hourly and 24-hour emissions using MOVES are TRANSVMT, VirtualLinkVMT, MOVESactivityInputBuild, MOVESpopulationBuild, MOVESfleetInputBuild, MOVESratesCalc, MOVESratesAdj, ShpExtIdleStartActBld, ExtIdleHrsCalc, MOVESemscal, and MOVESstabcomb. The TRANSVMT and VirtualLinkVMT prepare the link VMT and speeds activity input. The MOVESactivityInputBuild, MOVESpopulationBuild, and MOVESfleetInputBuild utilities build inputs used in MOVES. The MOVESratesCalc utility calculates the emissions rates from the MOVES output in terms of grams per activity, rather than the grams per vehicle emissions rates produced by MOVES. The MOVESratesadj utility makes special adjustments to the emissions rates when required. The ShpExtIdleStartActBld utility builds the SHP and starts activity required to estimate emissions using the grams per activity emissions rates produced by the MOVESratesCalc utility. The ExtIdleHrsCalc utility builds the SHI activity required to estimate emissions using the grams per activity emissions rates produced by the MOVESratesCalc utility. The MOVESemscal utility calculates emissions by hourly time periods, producing a tab-delimited summary file (including 24-hour totals) and hourly link emissions output files (optional). The MOVESstabcomb utility combines multiple MOVESemscal tab-delimited output files into one regional tab-delimited output file.

Process flow diagrams for both the TDM link-based hourly and HPMS/virtual link-based emissions estimation processes follow the utility descriptions.

TRANSVMT

The TRANSVMT utility post-processes travel demand models (TDMs) to produce hourly, on-road vehicle, seasonal and day-of-week specific, directional link VMT, and speed estimates. The

TRANSVMT utility processes a TDM traffic assignment by multiplying the link volumes by the appropriate Highway Performance Monitoring System (HPMS), seasonal, or other VMT factors. Hourly factors are then used to distribute the link VMT to each hour in the day. The TTI speed model is used to estimate the operational time-of-day link speeds for each direction. Since intrazonal links are not included in the TDM, special intrazonal links are created and the VMT and speeds for these special links are estimated using the intrazonal trips from the trip matrix and the zonal radii. The link VMT and speeds produced by TRANSVMT are subsequently input to the MOVESemscal utility for applying the MOVES-based emissions factors (as well as with other utilities to develop off-network activity estimates).

VirtualLinkVMT

The VirtualLinkVMT utility post-processes county HPMS average annual daily traffic (AADT) VMT, centerline miles, and lane miles by functional classification and area type (from the Texas Department of Transportation's [TxDOT's] annual Roadway Inventory Functional Classification Record [RIFCREC]) to produce hourly, on-road vehicle fleet, seasonal and day-of-week specific actual or projected VMT, and directional operational speed estimates. These estimated VMT and speeds are produced for up to 42 directional HPMS functional classification/area type combinations, or "links." The VirtualLinkVMT utility was developed for use in areas that do not have TDM networks, as well as for inventory applications for which network link-based detail is not required. The main inputs to VirtualLinkVMT are:

- County HPMS data sets, which include AADT VMT, centerline miles, and lane miles by HPMS area type and functional class;
- County-level VMT control totals;
- Hourly VMT distributions; and
- Speed model inputs to include volume/delay equation parameters adapted for HPMS, and free-flow speeds and lane capacities by HPMS functional classification and area type.

VirtualLinkVMT initially scales the county HPMS AADT VMT at the link level to the appropriate VMT (e.g., uses county-level VMT control total-to-AADT ratio to produce seasonal, day-of-week specific VMT). Hourly factors and directional split factors are applied to the adjusted VMT on each link to estimate the hourly, directional VMT (and volumes) by HPMS link. Congested speed models, each for the high- and low-capacity links, are used to estimate the hourly operational speeds by direction for each link. The operational speeds are based on

volume/capacity (V/C)-derived directional delay (minutes/mile) applied to the estimated free-flow speeds for each link. The virtual link VMT and speeds produced using the VirtualLinkVMT utility are an input to the emissions calculation utility, MOVESemscal (as well as with other utilities to develop off-network activity estimates).

MOVESactivityInputBuild

The MOVESactivityInputBuild utility builds the roadtypedistribution, hourvmtfraction, avgspeeddistribution, roadtype, hpmsvtypeyear, year, state, zone, zoneroadtype, monthvmtfraction, and dayvmtfraction data files in a format consistent with the MOVES input database tables using the link-based hourly VMT and speeds developed with the TRANSVMT or VirtualLinkVMT utility, the VMT mix, and the MOVES defaults. The primary inputs to this utility are:

- Link-based hourly VMT and speeds developed with the TRANSVMT or VirtualLinkVMT utility;
- County ID file which specifies the county number in the link-based hourly VMT and speeds for which the output will be calculated;
- VMT roadway type designations, which lists associations of the link roadway types/area type combination to the VMT mix, emissions rate, and MOVES roadway types (same as used with the MOVESemscal utility);
- 24-hour or Time Period VMT mix by roadway type, MOVES source type, and MOVES fuel type (same as used with the MOVESemscal utility);
- Day ID, which specifies the MOVES day ID for calculating the output;
- Year ID, which specifies the year for calculating the output;
- Link/Ramp designations, which designates each link roadway type/area type combination to either ramp or non-ramp; and
- MOVES default database.

For each link in the link-based hourly VMT and speeds in which the county number matches the desired county ID, the link VMT is saved in a VMT summary array based on hour, link functional class, and link area type. The link VHT (link VMT/link speed) is saved in a VHT summary array based on hour, link functional class, link area type, and MOVES average speed bin ID (determined using the MOVES average speed bins and the link speed). The link VHT is also saved in a road type VHT array based on link functional class and link area type, and, if the

link is specified as ramp by the link/ramp designations specified by the user, the VHT is additionally saved in the ramp segment of the road type VHT array.

A MOVES roadway type (which can include the additional roadway type 6 to include ramps) array by MOVES roadway type is also formed using the data in the VMT summary array and VMT roadway type designations. An hourly VMT array (by MOVES SUT, MOVES roadway type, and hour) is formed using the data in the VMT summary array, the VMT roadway type designations, and the VMT mix. If the time period VMT mix is used, each hour is assigned a time period by the user. Otherwise, the same 24-hour VMT mix is used for all hours. An average speed distribution array (by MOVES SUT, MOVES roadway type, hour, and MOVES speed bin) is created using the VHT summary array and the VMT mix. Using the appropriate MySQL code, the MOVES roadtypedistribution, hourvmtfraction, and avgspeeddistribution default values are extracted and saved for later use.

The VMT in the hour VMT array is aggregated by hour to produce the roadway type distribution array by MOVES SUT and MOVES roadway type. This VMT is then converted to a distribution by MOVES SUT (i.e., the total for a SUT over the five MOVES roadway types should equal 1), with the distribution value for MOVES roadway type 0 (Off-Network) equal to 0. Using the appropriate MySQL code, the roadtypedistribution database table is written. A tab-delimited version is also written (optional).

The VMT in the hourly VMT array is added to the hourly VMT fraction array (by SUT, MOVES roadway type, and hour) and for those roadway types where the VMT for all hours is greater than 0, this VMT is converted to an hourly distribution. For those roadway types where the VMT is equal to 0, a value of 1 is placed in the first hour, followed by 0 in the remaining hours. Using the appropriate MySQL code, the hourvmtfraction database table is written. For those SUTs where the VMT mix is greater than 0, the hourly VMT fraction array is used. Otherwise, the MOVES hourvmtfraction default values are used. A tab-delimited version is also written (optional).

The VHT in the average speed distribution array is converted to a distribution by SUT, MOVES roadway type, hour/day (combination of hour and the day ID specified by the user), and MOVES average speed bin. Using the appropriate MySQL code, the avgspeeddistribution database table is written. For those SUTs where the VMT mix is greater than 0, the average

speed distribution array is used. Otherwise, the MOVES avgspeddistribution default values are used. A tab-delimited version is also written (optional).

The VHT in the road type VHT array is converted to a proportion of ramp VHT by dividing the ramp segment of the road type VHT array by the total VHT for the road type in the road type VHT. Using the appropriate MySQL code, the road type database table is written using the proportions from the road type VHT array. A tab-delimited version is also written (optional).

The VMT in the hourly VMT array is aggregated to form the HPMS vehicle type VMT array. Each SUT is assigned an HPMS vehicle type (SUT 11 is HPMS vehicle type 10; SUT 21 is HPMS vehicle type 20; SUTs 31 and 32 are HPMS vehicle type 30; SUTs 41, 42, and 43 are HPMS vehicle type 40; SUTs 51, 52, 53, and 54 are HPMS vehicle type 50; and SUTs 61 and 62 are HPMS vehicle type 60). Using the appropriate MySQL code, the hpmsvtypeyear database table is written using the VMT from the HPMS vehicle type VMT array, along with the user supplied year ID, the VMT growth factor (automatically set to “Null”), and the base year Off-Network VMT (automatically set to 0). A tab-delimited version is also written (optional).

Using the appropriate MySQL code, the fuel year ID is extracted from the MOVES default year database table for the user-supplied year ID and the new year database table is written using the user-supplied year ID and the extracted fuel year ID. The “isbaseYear” data is written as well (automatically set to “Y”). A tab-delimited version is also written (optional).

The utility also produces two tab-delimited summary output files. A tab-delimited VMT summary is output by hour, link road type, and link area type for the user-specified county. A tab-delimited VHT summary is output by hour, link road type, link area type, and MOVES average speed bin for the user-specified county.

The utility outputs five other database tables (state, zone, zoneroadtype, monthvmtfraction, and dayvmtfraction) using the appropriate MySQL code and the user-supplied inputs. For the state database table, a new state database table is created and the data from the MOVES default state database table is copied to the new table for the state ID of 48. For the zone database table, a new zone database table is created and the data from the MOVES default zone data base table is copied to the new table for the county ID greater than 48000 and county ID less than 49000.

The start allocation factors, idle allocation factors, and SHP allocation factors are all then replaced with values of 1 in the new table.

For the zoneroadtype database table, a new zoneroadtype database table is created and the data from the MOVES default zoneroadtype data base table is copied to the new table for the zone ID greater than 480000 and zone ID less than 490000. The SHO allocation factors are all then replaced with values of 1 in the new table. For the monthvmtfraction database table, a new monthvmtfraction database table is created and the data from the MOVES default monthvmtfraction database table is copied to the new database table and the month VMT fraction is set to 1 for the user-supplied month ID and 0 for all other months. For the dayvmtfraction database table, a new dayvmtfraction database table is created and the data from the MOVES default dayvmtfraction database table is copied to the new and the day VMT fraction is set to 1 for the user-supplied day ID and 0 for all other months.

MOVESpopulationBuild

The MOVESpopulationBuild utility builds the sourcetypeyear data files in a format consistent with the MOVES input database table and the SUT/fuel type population input file (can be used with the MOVESemscalc utility to estimate emissions or the ShpExtIdleStartActBld utility to estimate starts and SHP) using the VMT mix and the Texas Department of Motor Vehicles (TxDMV) registration data sets. The TxDMV registration data sets are three sets of registration data (an age registration data file, a gas trucks registration data file, and a diesel trucks registration data file) that list 31 years of registration data. The primary inputs to this utility are:

- County ID file, which specifies the county for which the output will be calculated;
- Age registration data file, which lists 31 years of registration data for the Passenger Vehicle, Motorcycles, Trucks <=6000, Trucks >6000 <=8500, Total Trucks <=8500, Gas Trucks >8500, Diesel Trucks >8500, Total Trucks >8500, and Total All Trucks vehicle categories;
- Gas trucks registration data file, which lists 31 years of registration data for the Gas >8500, Gas >10000, Gas >14000, Gas >16000, Gas >19500, Gas >26000, Gas >33000, Gas >60000, and Gas Totals gas truck categories;
- Diesel trucks registration data file, which lists 31 years of registration data for the Diesel >8500, Diesel >10000, Diesel >14000, Diesel >16000, Diesel >19500, Diesel >26000, Diesel >33000, Diesel >60000, and Diesel Totals diesel truck categories;
- VMT mix by TxDOT district, MOVES SUT, and MOVES fuel type;

- TxDOT district name file, which specifies the VMT mix TxDOT district;
- MOVES default database;
- Population factor file (optional); and
- Year ID file (optional, only used if population factors are used), which specifies the year for calculating the output.

For the desired county (from the county ID file), the age registration data (for the Passenger Vehicle, Motorcycles, Trucks ≤ 6000 , Trucks $> 6000 \leq 8500$, and Total Trucks ≤ 8500 vehicle categories) are saved in an age registration data array. The gas truck registration data (for the Gas > 8500 , Gas > 10000 , Gas > 14000 , Gas > 16000 , Gas > 19500 , Gas > 26000 , Gas > 33000 , and Gas > 60000 gas truck categories) are saved in the gas truck section of the diesel/gas registration data array. The diesel truck registration data (for the Diesel > 8500 , Diesel > 10000 , Diesel > 14000 , Diesel > 16000 , Diesel > 19500 , Diesel > 26000 , Diesel > 33000 , and Diesel > 60000 diesel truck categories) are saved in the diesel truck section of the diesel/gas registration data array. The age registration data array and the diesel/gas registration data array are combined to form the registration category data array (seven categories for 31 years of data and the total) using the combinations in Table 6.

Table 6. Registration Categories.

Registration Category	Vehicle Category	Data Location
1	Passenger Vehicle	Age registration data array
2	Motorcycles	
3	Total Trucks ≤ 8500	
4	Diesel > 8500 , Diesel > 10000 , Diesel > 14000 , Diesel > 16000	Diesel/gas registration data array
5	Diesel > 19500 , Diesel > 26000 , Diesel > 33000 , Diesel > 60000	
6	Gas > 8500 , Gas > 10000 , Gas > 14000 , Gas > 16000	
7	Gas > 19500 , Gas > 26000 , Gas > 33000 , Gas > 60000	

The registration category data array is used to fill the SUT population array (by SUT and fuel type) for all vehicles except long-haul trucks. Each SUT/fuel type combination is assigned the total registrations from one or more of the registration categories in the registration category data

array. Table 7 shows the SUTs and their associated registration category in the registration category data array.

Table 7. SUT/Registration Category Correlation.

SUT	Registration Category
11	2
21	1
31, 32	3
41, 42, 43, 51, 52, 54	4 + 6
61	5 + 7

SUT population factors are calculated by SUT/fuel type using the data from the VMT mix input for all SUTs except motorcycles (SUT 11) and the long-haul trucks (SUTs 53 and 62) and saved in the SUT population factors array. For SUT 21, the fuel type VMT mix is divided by the total VMT mix for SUT 21. For SUT 31, the fuel type VMT mix is divided by the total VMT mix for SUTs 31 and 32. The same process applies to SUT 32. For SUT 41, the fuel type VMT mix is divided by the total VMT mix for SUTs 41, 42, 43, 51, 52, and 54. The same process applies to SUTs 42, 43, 51, 52, and 54. For SUT 61, the fuel type VMT mix is divided by the total VMT mix for SUT 61.

For SUT 11, the SUT population factor for fuel type 1 (gasoline) is set 1 with all other factors set to 0. For SUT 53, the SUT population factors by fuel type are calculated by dividing the fuel type VMT mix for SUT 53 by the fuel type VMT mix for SUT 52. For SUT 62, the SUT population factors by fuel type are calculated by dividing the fuel type VMT mix for SUT 62 by the fuel type VMT mix for SUT 61, therefore creating a ratio of long-haul and short-haul trucks.

The SUT population factors and the population factor (if desired) are applied to the SUT population array for all SUTs except SUT 53 and 62. For SUT 53, the SUT population factors for SUT 53 are applied to the SUT population array for SUT 52. For SUT 62, the SUT population factors for SUT 62 are applied to the SUT population array for SUT 61.

Using the appropriate MySQL code, a new sourcetypeyear database table is created. The data in the SUT population array is aggregated by fuel type and used to fill the sourcetypeyear database table, along with the yearID, salesGrowthFactor, and migrationrate. For the yearID, the year of the registration data is used, unless a population factor is used, in which case the year from the year ID input is used. The salesGrowthFactor and migrationrate for each SUT is set 1. A text format of this database table is written by the utility as well. The SUT/fuel type population input file is written using the SUT population array.

MOVESratesCalc

The MOVESratesCalc utility estimates emissions rates in terms of grams per activity (i.e., grams per mile, grams per SHP, grams per start, and grams per SHI) using the data in the movesoutput (emissions output) and movesactivityoutput (activity output) database tables produced by a MOVES emissions rate run. The utility also has the option of calculating the SHP, starts, and SHI activity per vehicle using the movesactivityoutput database table. If not specified, emissions rates are calculated for each pollutant and process combination (excluding total energy) in the movesoutput database table. The utility also uses the movesrun database table to determine the units of the emissions in the movesoutput table, which will then be converted to grams per activity during the emissions rate calculations; therefore allowing the user to specify any of the units available in MOVES for the MOVES emissions rate run. The type of activity used for the emissions rate calculation is determined by the process, as Table 8 shows.

Table 8. MOVES2010b Emissions Process and Corresponding Activity for Grams per Activity Emissions Rates.

MOVES2010b Emissions Process	Activity	Emissions Rate Units
Running Exhaust	Miles Traveled	Grams/Mile
Crankcase Running Exhaust	Miles Traveled	Grams/Mile
Start Exhaust	Starts	Grams/Start
Crankcase Start Exhaust	Starts	Grams/Start
Extended Idle Exhaust	Extended Idle Hours	Grams/Extended Idle Hour
Crankcase Extended Idle Exhaust	Extended Idle Hours	Grams/Extended Idle Hour
Evaporative Permeation	Miles Traveled Source Hours Parked	Grams/Mile Grams/ Source Hour Parked
Evaporative Fuel Vapor Venting	Miles Traveled Source Hours Parked	Grams/Mile Grams/ Source Hour Parked
Evaporative Fuel Leaks	Miles Traveled Source Hours Parked	Grams/Mile Grams/ Source Hour Parked
Brake Wear	Miles Traveled	Grams/Mile
Tire Wear	Miles Traveled	Grams/Mile

For the distance-based emissions rates (i.e., grams per mile), the utility extracts the emissions data (by pollutant, emissions process, roadway type, average speed bin, SUT, and fuel type) from the movesoutput database for the specified pollutants (or all of the pollutants if not specified) and the corresponding miles traveled activity (MOVES activityTypeID = 1) from the movesactivityoutput database table. The utility divides the emissions data by the corresponding activity data, applies the appropriate units conversion factor, and saves the emissions rates in the ttirateperdistance database table.

For the off-network emissions rates (i.e., grams per SHP, grams per start, and grams per SHI) the utility calculates the emissions rates based on the emissions process. For processID = 12 (evaporative fuel vapor venting), the utility extracts the emissions data (by hour, pollutant, emissions process, SUT, and fuel type) from the movesoutput database table for the specified pollutants (or all of the pollutants if not specified) where roadTypeID = 1 (“off-network” emissions) and the corresponding SHP activity (activityTypeID = 5) from the movesactivityoutput database table. The utility divides the emissions data by the corresponding

activity data, applies the appropriate units conversion factor, and saves the emissions rates in the `ttirateperactivity` database table.

Using the same calculation process, the utility also calculates the emissions rates for `processID = 17` (crankcase extended idle exhaust) and `processID = 90` (extended idle exhaust) using the corresponding SHI activity (`activityTypeID = 3`), for `processID = 11` (evaporative permeation) and `processID = 13` (evaporative fuel leaks) using the corresponding SHP activity (`activityTypeID = 5`), and for `processID = 2` (start exhaust) and `processID = 16` (crankcase start exhaust) using the corresponding starts activity (`activityTypeID = 7`).

For the SHP, starts, and SHI activity per vehicle, the utility extracts the SHP, starts, SHI, and population activity data (by hour, SUT, and fuel type) from the `movesactivityoutput` database table. The utility divides the SHP activity by the population and saves the SHP per vehicle in the `ttiaactpervehicle` database table. Using the same calculation process, the utility also calculates the starts per vehicle and SHI per vehicle using the starts and SHI activity data.

MOVESratesAdj

The `MOVESratesAdj` utility applies emissions rate adjustments to an emissions rate database table produced by `MOVES` (`rateperdistance`, `ratepervehicle`, `rateperprofile`), the `MOVESratesCalc` utility (`ttirateperdistance`, `ttirateperactivity`) or by this utility to produce a new emissions rate database table in the same format as the input emissions rate database table. The emissions rate adjustments can be linear adjustments that are applied to all emissions rates or can be applied by SUT, fuel type, pollutant, and process (adjustments may also include roadway type, average speed bin, and hour). The user has the option of selecting which pollutants will be in the new emissions rate database table. Otherwise, all of the pollutants in the input emissions rate database table will be in the new emissions rate database table. The utility also has the option for combining multiple emissions rate database tables into one new emissions rate database table, if the input emissions rate database tables are in the same format.

For the first input emissions rate database table, the utility extracts the emissions rates for the specified pollutants (or all the pollutants if not specified) from the input database emissions rate table, applies the emissions rate adjustments (if necessary) and saves these adjusted emissions rates. If more than one emissions rate database table is input, then the utility performs a similar calculation process to the first input emissions rate database table for each input emissions rate

database table. If pollutants are found in more than one input emissions rate database table, the adjusted emissions rates are summed to produce one emissions rate.

After processing all of the input emissions rate database tables, the utility creates a new emissions rate database table in the same format as the first input emissions rate database table and writes the adjusted emissions rates to this new emissions rate database table. A tab-delimited form of this database table may also be output that includes the text description of the pollutant, process, and roadway type instead of the MOVES codes that are included in the database tables.

ShpExtIdleStartActBld

The ShpExtIdleStartActBld utility calculates the SHP and starts activity by hour, SUT, and fuel type used to estimate emissions using the MOVESratesCalc emissions rates. The SHP is calculated using either the TDM or virtual link based link VMT and speeds (same as used in the distance-based emissions estimation), the 24-hour or time period VMT mix (by roadway type and SUT/fuel type), and the SUT/fuel type population (from the MOVESpopulationBuild). The starts activity is calculated using the SUT/fuel type population and the starts per vehicle (typically from the ttiactpervehicle database table created by the MOVESratesCalc utility). The utility also has the option of calculating the SHI activity used to estimate emissions using the MOVESratesCalc emissions rates. However, this method of estimating the SHI is a direct function of the SHO and does not consider the availability of locations where extended idling may occur. The suggested method for estimating the SHI is discussed in the “ExtIdleHrsCalc” section.

For each link in the first hourly VMT and speeds input that has the desired county code, the utility applies the appropriate VMT mix (either the 24-hour VMT mix or the appropriate time period VMT mix as assigned by the user) to distribute the link VMT to each SUT/fuel type, which is added to the hourly SUT/fuel type VMT. The link VMT by SUT/fuel type is divided by the link speed to calculate the link VHT (or SHO) by SUT/fuel type, which is added to the SUT/fuel type VHT. This calculation process is repeated for each VMT and speeds input; therefore producing 24-hourly values for VMT by SUT/fuel type and for VHT by SUT/fuel type.

The hourly SUT/fuel type speed, total hours (or source hours), and SHP are then calculated. For each hour and SUT/fuel type, the hourly SUT/fuel type VMT is divided by the hourly

SUT/fuel type VHT to calculate the hourly SUT/fuel type speed. The hourly SUT/fuel type total hours are set equal to the SUT/fuel type population. The hourly SUT/fuel type SHP are calculated by subtracting the hourly SUT/fuel type VHT (or SHO) from the hourly SUT/fuel type total hours.

The hourly SUT/fuel type starts are calculated using the hourly starts per vehicle and the SUT/fuel type population. For each hour, the hourly SUT/fuel type starts are calculated by multiplying the hourly starts per vehicle by the SUT/fuel type population.

The hourly SUT/fuel type SHIs are calculated for SUT 62, fuel type 2 (CLhT_Diesel) only. The CLhT_Diesel 24-hour SHI is calculated by multiplying the CLhT_Diesel 24-hour VHT (from the SHP calculation process) by the user-supplied extended idle factor, which represents the amount of extended idle time that must occur per SHO. The hourly CLhT_Diesel VHT (from the SHP calculation process) is converted to hourly VHT fractions. The hourly SHI fractions are calculated as the inverse of the hourly VHT fractions. The hourly SHI fractions are then applied to the CLhT_Diesel 24-hour SHI to calculate the hourly SUT/fuel type SHI.

ExtIdleHrsCalc

The ExtIdleHrsCalc utility calculates the SHI activity by hour for SUT 62, fuel type 2 (CLhT_Diesel) used to estimate emissions using the MOVESratesCalc emissions rates. This hourly SHI is calculated using a 24-hour base SHI for a specific year and day type, base link VMT and speeds, base 24-hour or time period VMT mix, future link VMT and speeds, future 24-hour or time period VMT mix, and the future tab-delimited hourly SHP by SUT/fuel type. All of the base data should be from the same year and day type. Although the term future data is used, the future data can be a year before the base data (i.e., historical year) and should be from the same year and day type. The tab-delimited hourly SHP by SUT/fuel type is typically the output from the ShpExtIdleStartActBld utility.

For each link in the first base VMT and speeds input that has the desired county code, the utility applies the appropriate base VMT mix (either the 24-hour VMT mix or the appropriate time period VMT mix as assigned by the user) for CLhT_Diesel to the link VMT to calculate the link CLhT_Diesel VMT, which is added to the hourly CLhT_Diesel VMT. The link CLhT_Diesel VMT is divided by the link speed to calculate the link CLhT_Diesel VHT, which is added to the hourly CLhT_Diesel VHT. This calculation process is repeated for each base

VMT and speeds input; therefore producing 24-hourly values for base CLhT_Diesel VMT and for base CLhT_Diesel VHT by SUT/fuel type. The same calculation process is performed for the future data (future VMT and speeds, future VMT mix) to calculate the hourly future CLhT_Diesel VMT and the hourly future CLhT_Diesel VHT.

The 24-hour future SHI is calculated using the 24-hour base CLhT_Diesel VMT, the 24-hour future CLhT_Diesel VMT, and the 24-hour base SHI. The scaling factor is calculated by the dividing the 24-hour future CLhT_Diesel VMT by the 24-hour base CLhT_Diesel VMT. The scaling factor is multiplied by the 24-hour base SHI to estimate the 24-hour future SHI.

The 24-hour future SHI is distributed to each hour using SHI hourly factors. The SHI hourly factors are calculated using the hourly CLhT_Diesel VMT. The hourly CLhT_Diesel VMT is converted hourly CLhT_Diesel VMT fractions. The SHI hourly factors are calculated by taking the inverse of the hourly CLhT_Diesel VMT fractions (i.e., more VMT implies less SHI). The SHI hourly factors are applied to the 24-hour future SHI to calculate the initial hourly future SHI, therefore distributing the 24-hour future SHI to each hour of the day.

To form the final SHI activity by hour, the initial hourly future SHI is compared to the hourly CLhT_Diesel SHP. If the initial hourly future SHI is greater than the hourly CLhT_Diesel SHP, then the final SHI activity for that hour is set to the hourly CLhT_Diesel SHP. Otherwise, the final SHI activity for that hour is set to the initial hourly future SHI. This comparison is performed for each hour.

MOVESemscal

The MOVESemscal utility estimates the hourly link emissions for one user-specified county using the emissions factors (either from MOVES, MOVESratesCalc or MOVESratesAdj), the 24-hour or time period VMT mix, the hourly link VMT and speeds activity estimates (either from TRANSVMT or VirtualLinkVMT), and the off-network activity (either vehicle population or SHP, starts, and SHI). This utility produces a tab-delimited output summary (including hourly and 24-hour totals) and hourly link emissions output files (optional). The primary inputs to MOVESemscal are:

- Emissions factors from MOVES, MOVESratesCalc or MOVESratesAdj;

- Link-based hourly VMT and speeds developed with the TRANSVMT or VirtualLinkVMT utility. For each link, the following information is input to MOVESemscal: link start node, link end node, link county number, link roadway type number, link area type number, link VMT, and link operational speed estimate;
- 24-hour or time period VMT mix by roadway type, MOVES SUT, and MOVES fuel type;
- Off-network activity. If the emissions factors are in grams per vehicle (i.e., the MOVES format), vehicle population by SUT/fuel type is required. If the emissions factors are in grams per activity (i.e., the MOVESratesCalc format), the SHP, starts, and SHI by hour and SUT/fuel type are required; and
- VMT roadway type designations, which lists associations of the link roadway types/area type combination to the VMT mix, emissions rate, and MOVES roadway types.

The emissions estimation can be categorized by two basic types based on the type of emissions factors: the roadway-based emissions and the off-network based emissions. For the roadway-based emissions (rateperdistance or ttirateperdistance emissions factors), the VMT for each link is distributed to each of the SUT/fuel type combinations listed in the VMT mix by roadway type (as designated in the VMT roadway type designations). If the time period VMT mix is input, each hour is assigned a time period by the user. Otherwise, the 24-hour VMT mix is used for all hours. The emissions factors are selected based on the emissions rate roadway type (as designated in the VMT roadway type designations) and the link speed for each SUT/fuel type combinations listed in the VMT mix. For link speeds greater than 75 mph, the emissions factors for 75 mph are used. For link speeds less than 2.5 mph, the emissions factors for 2.5 mph are used. For those link speeds that fall between the 16 MOVES speeds, the emissions factors are interpolated using the emissions factor interpolation methodology in the following section. These SUT/fuel type combination-specific emissions factors are multiplied by the SUT/fuel type combination-specific VMT to estimate the mobile source emissions for that link by SUT/fuel type combination.

The off-network emissions calculation depends on the format of the input emissions factors. If the emissions factors are in the MOVES format (rateperprofile and ratepervehicle), the emissions factors by SUT/fuel type are multiplied by their associated vehicle population to estimate emissions. If the emissions factors are in the MOVESratesCalc format, the emissions factors by SUT/fuel type are multiplied by the appropriate activity, which is determined by the emissions process (see Table 8).

The emissions estimates are output in a tab-delimited file (including all of the SUT/fuel type combinations listed in the VMT mix on a single line, separated by a tab character) for the specified county by pollutant, link roadway type, and SUT/fuel type combination for each of the specified episode time periods. A 24-hour (or total if all 24 hours are not specified) output is also included in the tab-delimited file. This tab-delimited file also includes hourly and 24-hour summaries of the off-network activity and VMT, VHT, and speed by link road type. Link emissions may also be output by county, pollutant, process, and each SUT/fuel type combination.

Emissions Factor Interpolation Methodology

To calculate emissions factors for link speeds that fall between two of the 16 MOVES speed bin speeds, an interpolation methodology similar to the methodology used with MOBILE6 is used. This methodology interpolates each emissions factor using a factor developed from the inverse link speed and the inverse high and low bounding speed bin speeds. The following is an example for a link speed of 41.2 mph.

The interpolated emissions factor (EF_{Interp}) is expressed as:

$$EF_{Interp} = EF_{LowSpeed} - FAC_{Interp} \times (EF_{LowSpeed} - EF_{HighSpeed})$$

Where:

$EF_{LowSpeed}$ = emissions factor (EF) corresponding to the speed below the link speed;

$EF_{HighSpeed}$ = EF corresponding to the speed above the link speed; and

$$FAC_{Interp} = \left(\frac{1}{Speed_{link}} - \frac{1}{Speed_{low}} \right) / \left(\frac{1}{Speed_{high}} - \frac{1}{Speed_{low}} \right)$$

Given that:

$EF_{LowSpeed}$ = 0.7413 g/mi;

$EF_{HighSpeed}$ = 0.7274 g/mi;

$Speed_{link}$ = 41.2 mph;

$Speed_{low}$ = 40 mph; and

$Speed_{high}$ = 45 mph.

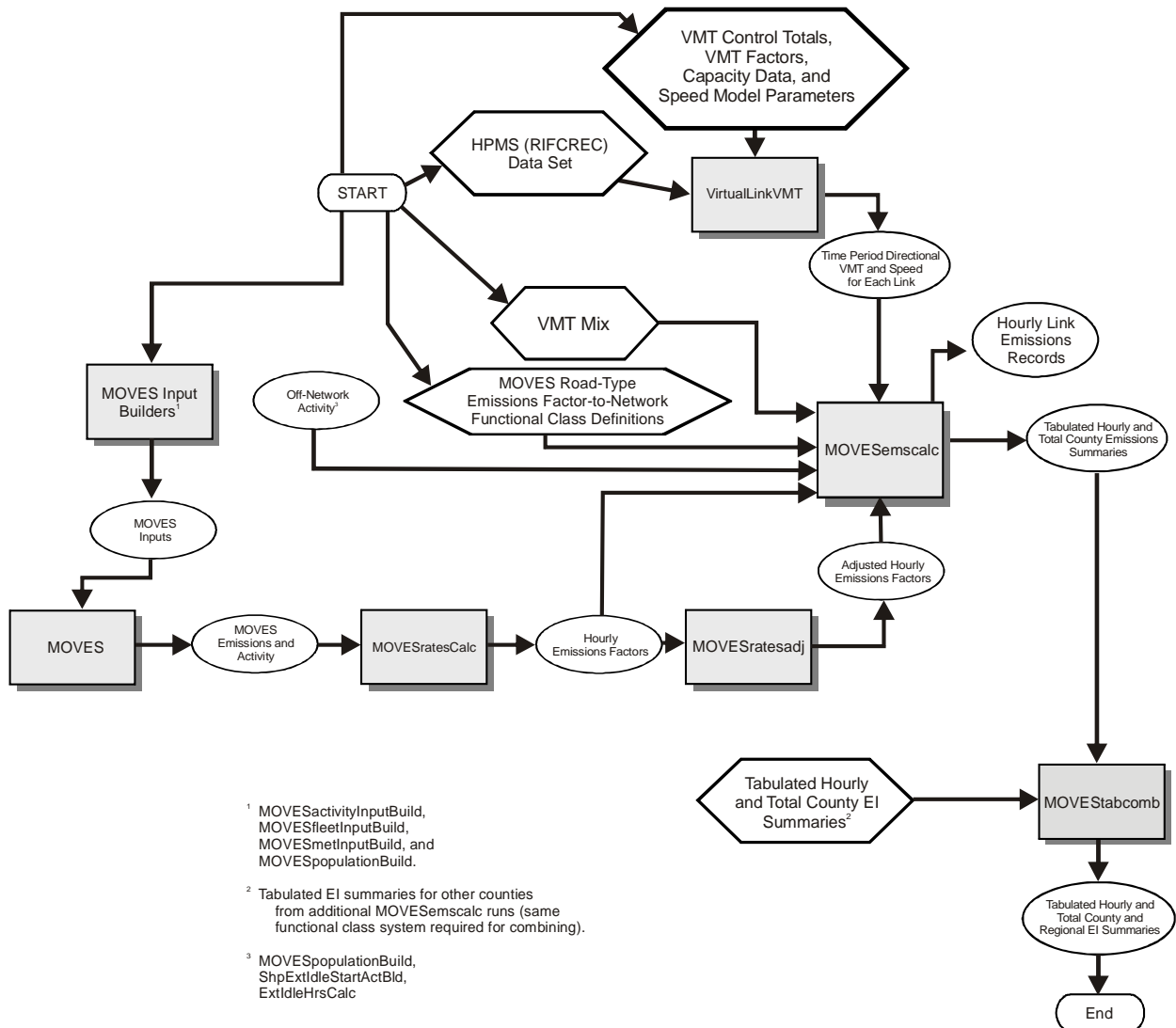
$$\begin{aligned} \text{FAC}_{\text{Interp}} &= \left(\frac{1}{41.2\text{mph}} - \frac{1}{40\text{mph}} \right) \bigg/ \left(\frac{1}{45\text{mph}} - \frac{1}{40\text{mph}} \right) = \frac{-0.00073}{-0.00278} = 0.26214; \\ \text{EF}_{\text{Interp}} &= 0.7413 \text{ g/mi} - (0.26214) \times (0.7413 \text{ g/mi} - 0.7274 \text{ g/mi}); \\ &= 0.7377 \text{ g/mi}. \end{aligned}$$

MOVEStabcomb

The MOVEStabcomb utility combines the tab-delimited output from multiple runs of the MOVESemscac utility to produce a regional summary of the VMT, VHT, speed (VMT/VHT), off-network activity, and emissions for each hour along with a 24-hour summary. A maximum of 1,000 tab files can be combined in one run of the MOVEStabcomb utility. However, each tab file must have the same roadway types or the utility will not function properly.

The new regional tab-delimited file is in the same form as the individual county files taken as input, except that each time period includes the individual county data summaries plus the regional summary. The individual county summaries are taken directly from the input tab-delimited files. The regional data summaries are summations of the county data except for “speed,” which is calculated as regional VMT/regional VHT.

HPMS / Virtual Link-Based Emissions Estimation Process



Travel Demand Model Network Link-Based Hourly MOVES Emissions Estimates

