

MOVES2014-BASED TRAVEL DEMAND MODEL LINK EMISSIONS ESTIMATION METHOD

Technical Guidance

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Version FY2018

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**MOVES2014a-BASED TRAVEL DEMAND MODEL LINK EMISSIONS
ESTIMATION METHOD**

Prepared for the
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Texas A&M Transportation Institute
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INTRODUCTION

The Texas A&M Transportation Institute (TTI) previously developed and implemented a detailed method for estimating emissions for counties included in travel demand models (TDM). As the U.S. Environmental Protection Agency’s (EPA) emissions factors models have evolved (the current version is MOVES2014b), so has this detailed on-road mobile emissions inventory method to accommodate these improvements in the emissions factors models. This method produces emissions inventories that are very valuable in the conformity analysis process.

OVERVIEW OF METHODOLOGY

TTI uses a detailed, MOVES rates-per-activity, TDM link-based, on-road mobile inventory method for emissions inventories involving counties included in TDMs. This method produces hourly emissions estimates for each link the TDM by vehicle type (Table 1), pollutant, and emissions process (Table 2) for each county inventory (more aggregate summaries are produced as well).

Table 1. MOVES Source Use Type/Fuel Types (Vehicle Types).

Source Use Type ID	Source Use Type Description	Source Use Type 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, or vehicle 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, respectively).

Table 2. MOVES Model On-Road Fleet 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
91	Auxiliary Power Unit Exhaust

The calculations and emissions for this method can be divided into two main categories: vehicle miles traveled (VMT)-based and off-network. For the VMT-based emissions, this method uses hourly TDM link-based summer weekday VMT and speeds and the MOVES rate-per-distance emissions rates. These emissions rates are produced directly by MOVES. For the off-network emissions, this method uses off-network activity and emissions rates specific to the off-network activity. The off-network activity consists of the vehicle starts, source hours parked (SHP), source hours idling (SHI or extended idle hours) and auxiliary power unit (APU) hours. All of the off-network emissions rates are directly available in MOVES, except for the SHP-based emissions rates that are produced using the TTI emissions inventory utilities (a description of these utilities is included in Appendix A). Table 3 shows emissions factors with associated processes and activity factors used.

Table 3. Emissions Rates by Process and Activity Factor.

Emission Processes	Activity¹	Emissions Factor²
Running Exhaust Crankcase Running Exhaust Brake Wear Tire Wear	VMT	mass/mile
Evaporative Permeation Evaporative Fuel Vapor Venting Evaporative Fuel Leaks	VMT	mass/mile
	SHP	mass/SHP
Start Exhaust Crankcase Start Exhaust	Starts	mass/start
Auxiliary Power Exhaust	APU hours	mass/APU hour
Extended Idle Exhaust Crankcase Extended Idle Exhaust	SHI	mass/SHI

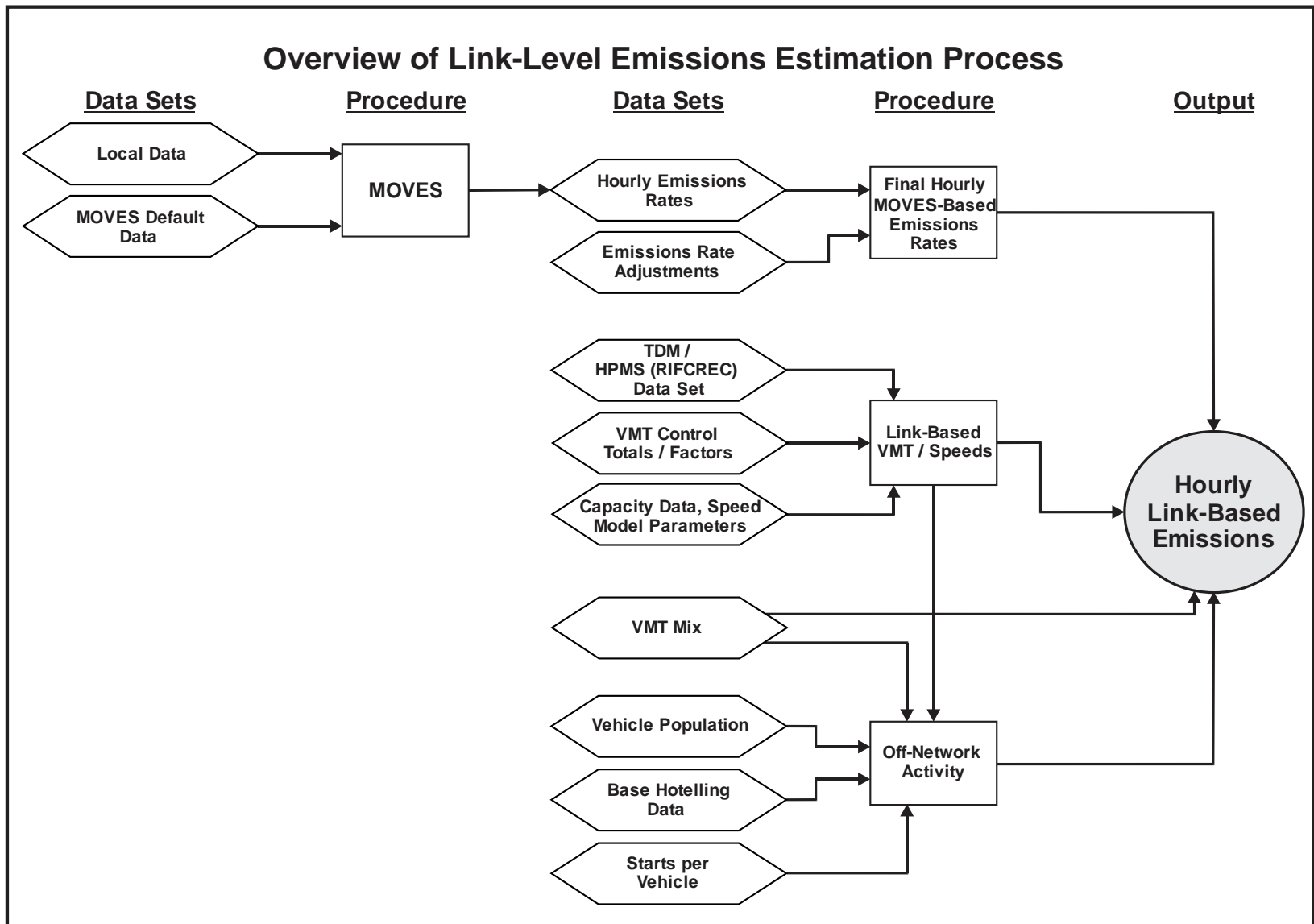
¹ SHI and APU hours are for combination long-haul trucks only.

² All of the rates are directly available from MOVES, except mass/SHP, which is produced by the TTI RatesCalc utility using MOVES rates mode input and output data.

The county emissions inventory estimation process requires development of the following major components. All are inputs to the emissions calculations, except vehicle populations, which are an intermediate input needed for calculating estimates of SHP and vehicle starts.

- District, four time-period VMT mix;
- Hourly, on-road fleet link VMT and average (operational) speeds;
- Vehicle type populations;
- Hourly vehicle type SHP;
- Hourly vehicle type starts;
- Hourly combination long-haul truck SHI and APU hours; and
- Hourly vehicle type VMT-based emissions rates (mass/mile) and off-network emissions rates (mass/SHP, mass/start, mass/SHI and mass/APU hour).

The TTI utilities used to develop or process these inventory components are outlined and described in Appendix A. Figure 1 shows an overview of the link-level emissions estimation process.



Source: Texas A&M Transportation Institute, October 2015.

Figure 1. Link-Level Emissions Estimation Process Overview.

VMT Mix

VMT mix designates the vehicle types included in the analysis, and specifies the fraction of on-road fleet VMT attributable to each vehicle type by MOVES road type. The MOVES model categorizes the fleet based on nine different fuel types and 13 different source use types (SUTs).

VMT mix is estimated based on TTI's 24-hour average VMT mix method, expanded to produce the four-period, time-of-day estimates.¹ The VMT mix method sets Texas vehicle registration category aggregations for MOVES SUT categories to be used in the VMT mix estimates, as well as for developing other fleet parameter inputs needed in the process (e.g., vehicle age distributions). The current VMT mix method produces a set of four time-of-day period average vehicle type VMT allocations by MOVES road type, by the four day types, estimated for each Texas Department of Transportation (TxDOT) district for use with the counties associated with each district. The data sources used are recent, multi-year TxDOT vehicle classification counts, year-end TxDOT/Texas Department of Motor Vehicles (TxDMV) registration data, and MOVES default data, where needed.

On-Road Fleet Link-VMT and Speeds

Summer weekday VMT and average operational speed inputs are required for the roadway-based calculations (product of “per mile” rates and VMT). TTI uses data sets extracted from the TDMs, VMT adjustment factors (Highway Performance Monitoring System [HPMS] and/or seasonal day-type adjustments), and hourly allocation factors to estimate the hourly, directional, link-VMT and associated average fleet speed inputs. The seasonal and hourly distributions used are based on factors developed with TxDOT automatic traffic recorder (ATR) data. The hourly average operational fleet speeds are estimated corresponding to the link VMT estimates using the either the TTI speed model (estimates operational speeds based on the link estimated free-flow speed and estimated directional delay) or the Houston speed model (estimates operational speeds based on a link's estimated free-flow speed and congestion-related speed reduction), depending on the TDM area.

Vehicle Population and Off-Network Vehicle Activity Estimates

The non-roadway, travel-related, on-road mobile source emissions estimates (e.g., from vehicle starts, parked vehicle evaporative processes, hotelling activity consisting of extended idling and APU usage) are calculated as the product of the amount of associated activity and the pollutant mass per unit of activity (emissions factor terms as shown in Table 3). To estimate the SHP and vehicle starts activity, SUT/fuel type category population estimates are needed. Hotelling activity estimates (comprising the SHI and APU hours) are based on county-specific actual estimates.²

Vehicle Type Populations: TTI based the vehicle population estimates on vehicle registration data, vehicle population factors derived from the VMT mix, and, additionally for future years, VMT growth estimates. For a historical year, the vehicle type vehicle population estimates are based solely on mid-year TxDOT (or TxDMV) county registrations data and regional, all roads-

¹ *Methodologies for Conversion of Data Sets for MOVES Model Compatibility*, TTI, August 2009, and *Update of On-Road Inventory Development Methodologies for MOVES2010b*, TTI, August 2013.

² *Heavy-Duty Vehicle Idle Activity and Emissions Characterization Study*, ERG, August 2004.

weekday VMT mix-based population factors for the analysis year. For a future year, vehicle type populations are estimated as a function of base (e.g., latest available, mid-year) registrations, grown to a future value (growth as a function of base and future VMT as estimated under the virtual-link VMT forecasting method), and all roads-weekday vehicle type VMT mix-based population factors for the analysis year.

SHP: The SHP is estimated as a function of total hours (hours a vehicle exists) minus its hours of operation on roads (source hours operating [SHO], which is the same as vehicle hours traveled [VHT]). For a historical year, the vehicle type SHP estimates are based on VMT mix, link VMT and speeds, and the vehicle population estimates. The VMT mix is applied to the link VMT to produce vehicle type-specific VMT estimates. Link VMT is divided by the associated speed to produce SHO estimates, which are subtracted from source hours resulting in SHP estimates. For a future year, the vehicle type SHP is estimated in the same manner as for historical years, except using the future year link VMT and speeds, VMT mix, and the vehicle population estimates. This is performed for each county by hour and activity scenario.

Starts: Engine starts are based on the MOVES national default starts per vehicle, and the local, county vehicle type population estimates. MOVES default weekday and weekend day starts per vehicle are used. The starts are calculated as the product of starts/vehicle from MOVES, and the county vehicle type population estimates. This is performed by county and hour, for each MOVES day type.

SHI and APU Hours: The SHI and APU hours comprise the diesel combination long-haul truck hotelling hours, estimated based on information from the Texas Commission on Environmental Quality (TCEQ) *Extended Idling Study* (ERG, August 2004), and additional factors developed by TTI. Hotelling activity for a 2004 base year is derived from the 2004 idle activity study summer weekday extended idling hours estimates by Texas county. TTI uses summer weekday 24-hour 2004 base hotelling estimates derived from this study in combination with summer weekday 2004 base year and inventory analysis year link VMT and VMT mix (for each activity scenario) to produce county, hourly hotelling activity estimates for each activity scenario. Hotelling hourly factors (estimated by inverting hourly VMT factors) are then applied to allocate the 24-hour hotelling hours estimates for each activity scenario to each hour of the day. Estimated proportions of SHI and APU hours are used to divide hourly hotelling hours into SHI and APU hours activity.

MOVES Emissions Factors

TTI produces the emissions rate look-up table inputs to the inventory calculations in three basic steps: set up and execute the MOVES emissions rate mode runs; perform the initial post-processing, which calculates rates in the form needed that are not directly available from MOVES; and perform the final post-processing to make needed adjustments and screen out non-applicable pollutants.

Local input parameters are developed and used to produce rates reflective of the local scenario conditions (e.g., weather and fleet characteristics, fuel properties, I/M program). MOVES county scale, rates mode modeling scenarios produce rates for the weekday MOVES day type by pollutant, process, speed (for roadway-based processes), hour, road type, and average SUT/fuel type. Two rates post-processing steps are performed to produce the final rates

in the form needed. MOVES data are post-processed to produce the mass-per-SHP form of off-network evaporative rates not available from MOVES, and to tabulate them along with the other MOVES-produced activity-based rates (mass/mile, mass/hour, mass/start) into rate look-up table databases. The final rates post-processing step extracts the rates needed in the inventory calculations (i.e., screens out any unneeded pollutants/processes remaining from the previous step), and makes any required adjustments (i.e., applied estimated Texas Low-Emissions Diesel [TxLED] effects on diesel vehicle NO_x [and NO_x sub-component pollutant] rates for covered counties).

Inventory Calculations

Summer weekday inventories are calculated for each county using the previously described major inputs: TxDOT district-level, day type, time-of-day, VMT mix by MOVES road type; summer weekday county, hourly on-road fleet link VMT and speed estimates; summer weekday county, hourly, off-network activity estimates by vehicle type for each activity scenario, of SHP, starts, SHI and APU hours (for combination long-haul trucks [CLHT] diesel only); and county-level look-up tables of hourly rates by MOVES day type, road type, speed bin, vehicle type (SUT/fuel type) and process.

For the VMT-based calculations, county-to-TxDOT district, TDM road type/area type-to-MOVES road type, and hour-of-day to time-of-day period designations are used to match the appropriate VMT mixes with the link VMT. The VMT mixes by MOVES road type are multiplied by the link fleet VMT to distribute each link's VMT to the different vehicle type categories. Emissions rates for each link's average speed are interpolated (see the procedure in the appendix) from the appropriate set of look-up table emissions factors and corresponding index speeds (i.e., the average bin speeds of 2.5, 5.0, 10.0, 15.0, ... 75.0 mph), bounding the link's average speed. For link speeds below or above the minimum and maximum average bin speeds of 2.5 and 75 mph, the rates for those bounding speeds are used. The estimated vehicle type and MOVES road type link speed-specific emissions factors for each pollutant process are then multiplied by the associated VMT to produce the link-based emissions estimates. This process is performed for each county, hour, and activity scenario.

For the off-network calculations, which are county level, the vehicle type, county-level rates are multiplied by the associated county total activity estimate, as determined by the pollutant process. This process is performed for each county, hour, and activity scenario.

TTI developed and maintains a series of computer utilities to calculate and summarize detailed on-road mobile source emissions inventories in various formats. The appendix describes these applications.

DEVELOPMENT OF VMT MIX

VMT mix is a major input to the MOVES link-based emissions estimation process. It is an estimate of the fraction of on-road fleet VMT attributable to each SUT by fuel type, and is used to subdivide the total VMT estimates on each link into VMT by vehicle type. These hourly VMT estimates by vehicle type are combined with the appropriate emissions factors in the link-emissions calculations.

On-road mobile emissions are dependent upon the VMT assigned to each vehicle category. The VMT mix is used to distribute link VMT values to each vehicle category. Since the VMT mix can vary by time-of-day (and thus have an effect of the emissions totals), the TTI VMT mix procedure allows the option to develop VMT mix by time period. Time period VMT mix (by MOVES roadway type and vehicle type) consists of four time periods: morning rush hour (AM peak), mid-day, evening rush hour (PM peak), and overnight.

TxDOT district-level, time period, Weekday (average Monday through Thursday), Friday, Saturday, and Sunday vehicle type VMT mixes (for gasoline-powered and diesel-powered vehicles) are estimated by the four MOVES road-type categories using the methodology characterizing VMT by vehicle type for a region (or district) as follows.³

1. MOVES – Data files of MOVES default values extracted from MOVES databases or pro forma runs.
2. TxDOT Classification Counts – Data files of standard TxDOT classification data assembled and used for determining the in-use road fleet mix.
3. TxDMV Registration Data – Data files of standard TxDMV vehicle registration summary data assembled and used for determining the in-use road fleet mix.
4. TxDOT ATR Data – Data files of TxDOT ATR data assembled and used to allocate VMT by season and day of week.
5. Single Unit Local vs. Total SUT_HDVyy – Procedure based on registration data to generate factors to separate Single Unit versus Combined Unit trucks by region. (SUT_HDVyy has multiple outputs based on vehicle category and fuel.)
6. Combination Local vs. Total SUT_HDXyy – Procedure based on registration data to generate short-haul and long-haul combination truck proportions by region.
7. Day of Week (DOW) Factors by Urban Area/TxDOT District – Seasonal day-of-week factors from TxDOT ATR data used to allocate VMT by season and day-of-week by urban area/TxDOT district.
8. Single Unit Short-Haul vs. Long-Haul SUT_SSHZ – Procedure to separate single unit short-haul versus single unit long-haul using factors generated at SUT_HDVyy and classification count data. Short-haul and long-haul are functionally defined as local and pass through.
9. Combination Short-Haul vs. Long-Haul SUT_CSHZ – Procedure to separate combined short-haul versus combined long-haul using factors generated at SUT_HDXyy and classification count data. Short-haul and long-haul are functionally defined as local and pass through.

³ The 24-hour VMT mix estimation methodology is documented in the report entitled, *Methodologies for Conversion of Data Sets for MOVES Model Compatibility*, TTI, August 2009; *Update of On-Road Inventory Development Methodologies for MOVES2010b*, TTI, August 2013, documents revisions of utilities to incorporate the time-of-day VMT mixes.

10. PV and LDT Fuel MF_Fuelyy – Procedure to generate passenger vehicle and light truck fuel allocation by year based on MOVES national default values and local registration data.
11. Single Unit and Combination Truck Fuel SUT_HDVyy – Procedure to generate single unit and combined truck fuel allocation factors from registration data. (SUT_HDVyy has multiple outputs based on vehicle category and fuel.)
12. SUT_yyddtt – Procedure to generate SUT proportions by year, day type, and time period, based on the previous steps.
13. MOVES SUTs – Output file of MOVES SUTs by region, analysis year, day type, and time period.

Figure 2 provides an overview of the VMT mix process.

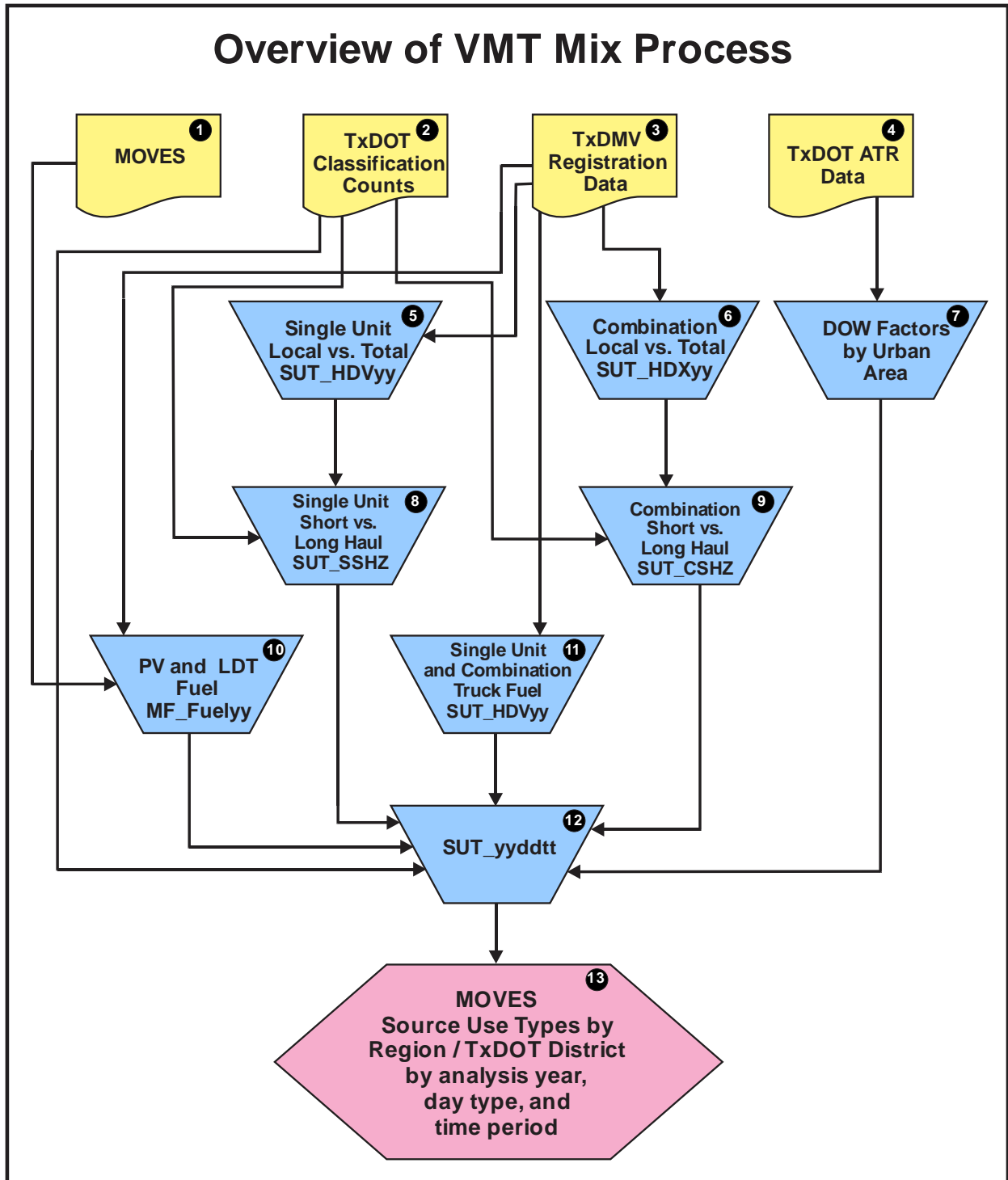


Figure 2. Overview of the VMT Mix Process.

TxDOT district-level weekday vehicle type VMT mixes by MOVES road-type category are produced based on recent multi-year vehicle classification counts and appropriate end-of-year TxDOT vehicle registrations data. Using the same data sets and a similar procedure, aggregate (i.e., all road-type categories) TxDOT district-level weekday vehicle type VMT mixes (used in

the vehicle population estimation) are also produced. To ensure general applicability and consistency across all study areas, all VMT mixes are developed in five-year increments beginning with the year 2005 and applied to the analysis years based on Table 4.

Table 4. VMT Mix Year/Analysis Year Correlations.

VMT Mix Year	Analysis Years
2005	2003 through 2007
2010	2008 through 2012
2015	2013 through 2017
2020	2018 through 2022
2025	2023 through 2027
2030	2028 through 2032
2035	2033 through 2037
2040	2038 through 2042
2045	2043 through 2047
2050	2048 +

ESTIMATION OF VMT

The TDM link-based emissions process requires VMT estimates by hour and direction for each link in the TDM, as well as intrazonal VMT that are not accounted for in the TDM. This process also requires that VMT be adjusted for HPMS consistency and to reflect estimated levels characteristic of a typical summer weekday. The TRANSVMT utility (see Appendix A for a description of the utility), latest available TDM data sets, and post-processing factors developed from several other data sources are used to produce this summer weekday hourly VMT by direction.

Data Sources

The latest available TDM link data, trips data, and zonal radii data sets are used to estimate the directional link VMT and speeds by hour. Since intrazonal VMT are not accounted for in the TDMs, the intrazonal VMT was estimated using the TDM's trip matrix and zonal radii data sets. The TDM link data and trips data can be from a 24-hour TDM assignment or a time period TDM assignment.

Several other data sources are used to adjust the VMT for HPMS consistency and to estimate the summer weekday VMT. The first data source is HPMS VMT estimates, which are based on traffic count data collected according to a statistical sampling procedure specified by the Federal Highway Administration (FHWA) designed to estimate VMT. The county total HPMS Annual Average Daily Traffic (AADT) VMT is used to ensure the travel model VMT is consistent with

the HPMS VMT estimates. (EPA and FHWA have endorsed HPMS as the appropriate source of VMT and require that VMT used to construct on-road mobile source emissions estimates be consistent with that reported through HPMS.)

The second data source is ATR vehicle counts, which are collected by TxDOT at selected locations throughout Texas on a continuous basis. These vehicle counts are available by season, month, and weekday, as well as on an annual average daily basis (i.e., AADT). The counts are very well suited for making seasonal, day-of-week, and time-of-day comparisons (e.g., seasonal adjustment and hourly allocation factors), even though there may be relatively few ATR data collection locations in any given area.

Multiple years of data from the ATR stations are typically grouped at different aggregation levels, depending upon the purpose. This data source is used to produce the day-type-specific adjustment factor, in which the data from within the TxDOT district are aggregated (one factor per TxDOT district with all counties within the district using the same factor). This data source is also used to produce the time-of-day (hourly) allocation factors, in which the data from the ATR stations within the region covered by the TDM are aggregated.

VMT Adjustments

For each analysis year, the TDM VMT is adjusted for HPMS consistency and for seasonality (i.e., summer weekday). For a historical year (i.e., HPMS VMT data exists for those years), county-level summer weekday VMT control totals are used to develop VMT adjustment factors, which are applied to the TDM. For a future year (i.e., HPMS VMT data does not exist), a regional HPMS factor and seasonal day-type specific (summer weekday) factors are used. In the event a TDM does not exist for an analysis year, intermediate year factors can be developed using the bounding TDMs and applied to the analysis year's respective TDM. Hourly travel factors are also applied to distribute this adjusted VMT over each hour of the day.

Historical Year Analysis – VMT Control Totals and VMT Adjustments

To estimate the historical HPMS-consistent summer weekday VMT, county-level summer weekday VMT control totals are used to develop county-level VMT adjustment factors. The VMT control totals are comprised of two key components: the analysis year county-level HPMS AADT VMT and the AADT-to-summer weekday adjustment factor.

The AADT-to-summer weekday adjustment factor is developed using the most recent, aggregated ATR data. This factor (developed by TxDOT district, with each county within the district using the same factor) is calculated by dividing the average day-of-week count by the AADT traffic count.

The county summer weekday VMT control totals are developed by multiplying the county HPMS AADT VMT for the analysis year by the appropriate summer weekday adjustment. County-level VMT adjustment factors are calculated by dividing each county's respective control total by the total VMT (TDM assignment VMT plus intrazonal VMT estimate) from the analysis year TDM. For each link in the TDM, the link volume is multiplied by the corresponding VMT adjustment factor (based on the county where the link is located). The adjusted link volumes are then multiplied by the associated link lengths to produce the link-level HPMS consistent, summer weekday VMT estimates.

Future Year Analyses – HPMS Adjustment Factor

For future year analyses (those years where HPMS data is not available), an HPMS adjustment factor is used to adjust the total VMT (TDM assignment VMT plus intrazonal VMT estimate) for HPMS consistency. This factor is developed using the regional total VMT from the validated TDM and the regional HPMS AADT VMT for the same year as the validated TDM. Since the TDM is average non-summer weekday traffic (ANSWT) and the HPMS VMT is AADT, an AADT-to-ANSWT factor is used to make the conversion and consistency between the TDM and HPMS VMT components of the HPMS factor. This factor is developed using multiple years of ATR data from stations within the TDM area. The HPMS factor calculation can be described using the following formula:

$$\text{Region HPMS VMT (AADT)} \times \text{AADT-to-ANSWT factor} = \text{Region HPMS VMT (ANSWT)}$$
$$\text{Region HPMS VMT (ANSWT)} / \text{Region TDM VMT (ANSWT)} = \text{HPMS Factor}$$

Future Year Analyses – Seasonal Adjustment Factors

For the future year analyses, seasonal adjustment factors are used to adjust the TDM and estimated intrazonal VMT to summer weekday VMT. The seasonal adjustment factors are developed using multi-year, aggregated ATR data by TxDOT district. These factors are calculated by dividing the average day-of-week (weekday) count by the annual non-summer weekday traffic (ANSWT) traffic count.

Future Year Analyses – Intermediate Year Adjustment Factors

Subject to concurrence with the consultation partners, intermediate year adjustment factors are used for those analysis years where a TDM does exist to estimate the analysis year VMT from an existing TDM. These adjustment factors are developed using the bounding year TDMs and applied to the specified TDM. The intermediate year adjustment factors are based on the annually compounded growth rates between the bounding year TDMs. The annual growth rates are then converted into the intermediate year adjustment factors using the following equation:

$$\text{Intermediate Year Adj. Factor} = \text{Growth Rate}^{\text{Target Year} - \text{Base Year}}$$

Where:

- Target Year = the desired intermediate year;
- Base Year = the year of the TDM used for estimating the VMT; and
- Growth Rate = the annual growth rate from the range of TDM years encompassing the Target Year.

Since each county grows at a different rate, these factors are developed by county to maintain this relationship between the bounding TDMs. For time-period TDMs, these adjustment factors are also developed by time period (one factor per county and time period) to maintain the relationship between the time periods.

Future Year Analyses – Overall VMT Adjustments

For each future year, the final HPMS-consistent, summer Weekday VMT is comprised of two parts: the link-level VMT and the estimated intrazonal VMT. The volume for each link is multiplied by the HPMS factor, the seasonal adjustment factor, and the link's respective length to

estimate the link-level VMT (hourly factors are also applied to distribute the resulting VMT over each hour of the day, discussed in a later section). The HPMS and seasonal adjustment factors (as well as the hourly factors mentioned previously) are also applied to the estimated intrazonal VMT. If necessary, the appropriate intermediate year VMT factors are also applied to the volume for each link prior to the VMT calculation and to the estimated intrazonal VMT.

Hourly Travel Factors

Hourly travel factors are used to distribute the TDM and intrazonal VMT to each hour of the day. These hourly travel factors are developed using multi-year ATR station data aggregated for the region. For time period TDMs, the hourly fractions are normalized within each time period to maintain VMT proportions within each of the time periods. Each factor (i.e., 24, or one for each hour of the day) is multiplied by the link volume (in addition to the other VMT adjustment factors). These adjusted link volumes are multiplied by their respective link lengths to estimate the link level, summer weekday VMT estimates for each hour. These factors are also multiplied by the estimated intrazonal VMT to produce the final hourly-adjusted VMT.

ESTIMATION OF LINK SPEEDS

The link-level operational speeds required to calculate the VMT-based emissions are calculated using either the TTI speed model or the Houston speed model. The TTI speed model is used for all TDM areas other than Houston, where the Houston speed model is used.

TTI Speed Model

To estimate link operational (congested) speeds, a speed model involving both the link estimated free-flow speed and estimated directional delay (as a function of volume and capacity) is used. This model is used to estimate the hourly, directional, congested speed for each link, except for the TDM centroid connectors and added intrazonal links. The congested speed is calculated using the following formula:

$$Congested\ Speed = \frac{60}{\frac{60}{Freeflow\ Speed} + Delay}$$

Typically, free-flow speed factors are used to convert TDM speeds (which are by definition level of service [LOS] C) to LOS A speeds (free flow). These free-flow speed factors vary by TDM area and are calculated by dividing the free-flow speed by the speed from the speed/capacity look-up table (same table used in the TDM) for each functional class (or facility type, depending on the TDM area) and area type combination. The free-flow speeds are determined using the Highway Capacity Manual (HCM), using suitable assumptions to relate the HCM data to the functional classes (or facility types) used in the TDMs. However, if the coded speeds in the TDMs are designated as free-flow speeds, free-flow speed factors are not required.

The second component of the speed model is the estimated directional delay. The directional delay (in minutes per mile) due to congestion is calculated using the following volume/delay equation:

$$Delay = Min \left[A e^{B \left(\frac{V}{C} \right)}, M \right]$$

Where:

- Delay = congestion delay (in minutes/mile);
- A & B = volume/delay equation coefficients;
- M = maximum minutes of delay per mile; and
- V/C = time-of-day directional volume-to-capacity (v/c) ratio.

The delay model parameters (A, B, and M) were originally developed for the Dallas/Fort Worth area and verified by application in other Texas urban areas. These parameters (shown Table 5) are applied based on the functional classes (facility types, depending upon the TDM area) used in the TDM (except for centroid connector and intrazonal, which do not use capacity data).

Table 5. Volume/Delay Equation Parameters.

Facility Category	A	B	M
High-Capacity Facilities	0.015	3.5	5
Low-Capacity Facilities	0.050	3.0	10

The time-of-day directional v/c ratios are estimated using the directional volume (from the VMT estimation) and the time-of-day directional capacity. However, the TDM assignments may contain non-directional time period or 24-hour capacities. To estimate the time-of-day directional capacity, the directional split for capacity is assumed 50/50 for non-directional TDM assignments (no split is required for directional assignments) and capacity factors are multiplied by the TDM link capacity. For the time period TDM assignments, capacity factors are typically calculated as the inverse of the number of hours in the time period. For 24-hour TDM assignments, capacity factors are calculated using the following formula:

$$Capacity\ Factor = \frac{(Hourly\ Capacity\ per\ Lane)(Length\ of\ the\ Time\ Period)}{24 - Hour\ Capacity\ per\ Lane}$$

Capacity data are not used, however, for the centroid connector links and the added intrazonal links (added specifically for these emissions inventories). The centroid connector traffic assignment input speeds are used as the centroid connector operational speeds estimates. Operational speeds for the intrazonal trips category are estimated by zone as the average of the zone's centroid connector speeds.

Houston Speed Model

Using the Houston speed model, the operational speeds are calculated for each link, excluding centroid connectors and the special intrazonal links. The Houston speed model calculates these speeds using the travel model speed, speed factors (consisting of a free-flow speed factor and LOS E speed factor) and a v/c ratio-based speed reduction factor (SRF) for each link.

The speed factors are used to convert the link-level travel model (input) speed to a free-flow speed and an LOS E speed (i.e., application of these factors results in two speeds). The free-flow speed factors (grouped by functional class and area type) are calculated by dividing the distance-weighted free-flow speed by the distance-weighted input speed for each functional class/area type combination. The distance-weighted free-flow speeds are calculated using output from the detailed speed model used by the Houston-Galveston Area Council (H-GAC) in the travel model development process with link volumes set to 0 (i.e., $v/c = 0$). The LOS E speed factors are calculated in a similar manner (distance-weighted LOS E speed divided by distance-weighted input speed) using the detailed speed model output with link volumes set equal to capacity (i.e., $v/c = 1$).

The link-specific v/c ratio is calculated as the time period (hourly) volume divided by the time period capacity. The v/c ratio is expressed as:

$$v/c \text{ ratio} = V_h / C_h$$

Where:

V_h = the hourly link volume (travel model \times HPMS factor \times seasonal adjustment factor \times hourly time period factor; Weekend profile factor is included for Saturday and Sunday); and

C_h = the hourly link capacity (travel model capacity \times hourly capacity factor).

After the v/c ratio is calculated, the link-specific SRF is determined using the v/c ratio, the link-specific SRF area type, the link-specific SRF functional class, and the SRFs. The SRFs are for v/c ratios of 0 to 1 in 0.05 increments (i.e., 0, 0.05, 0.10, ... , 0.95, 1.0). The link-specific SRF is calculated using linear interpolation. For v/c ratios greater than 1.0, a SRF is not required.

The speed model (for v/c ratios from 0.00 to 1.00) is expressed as:

$$S_{v/c} = S_{0.0} - \text{SRF}_{v/c} \times (S_{0.0} - S_{1.0})$$

Where:

$S_{v/c}$ = estimated directional speed for the forecast v/c ratio on the link in the given direction;

$S_{0.0}$ = estimated free-flow speed for the v/c ratio equal to 0.0;

$S_{1.0}$ = estimated LOS E speed for the v/c ratio equal to 1.0; and

$\text{SRF}_{v/c}$ = SRF for the v/c ratio on the link. The v/c ratio can be 0.0 to 1.0.

For v/c ratios greater than 1.0 and less than 1.5, the following speed model extension is used:

$$S_{v/c} = S_{1.0} \times (1.15 / (1.0 + (0.15 \times (v/c)^4)))$$

Where:

$S_{v/c}$ = estimated directional speed for the forecast v/c ratio on the link in the given direction;

$S_{1.0}$ = estimated LOS E speed for the v/c ratio equal to 1.0; and

v/c = the forecast v/c ratio on the link. The v/c ratio can be 1.0 to 1.5.

For v/c ratios greater than 1.5, the speed is calculated using the previous speed model extension, except the v/c ratio was set to 1.5.

These speed models are applied to all functional classes excluding the centroid connector and intrazonal functional classes. For these functional classes, capacity data are not used. The centroid connector travel model input speeds are used as the centroid connector operational speeds estimates. Operational speeds for the intrazonal functional class are estimated by zone as the average of the zone's centroid connector speeds.

ESTIMATION OF OFF-NETWORK ACTIVITY

To estimate the off-network (or parked vehicle) emissions, county-level estimates of the SHP, starts, SHI, and APU hours are required by hour and vehicle type for each inventory year (SHI and APU hours are for diesel combination long-haul trucks only). One of the main components of the SHP and starts off-network activity estimation is the analysis year county-level vehicle population.

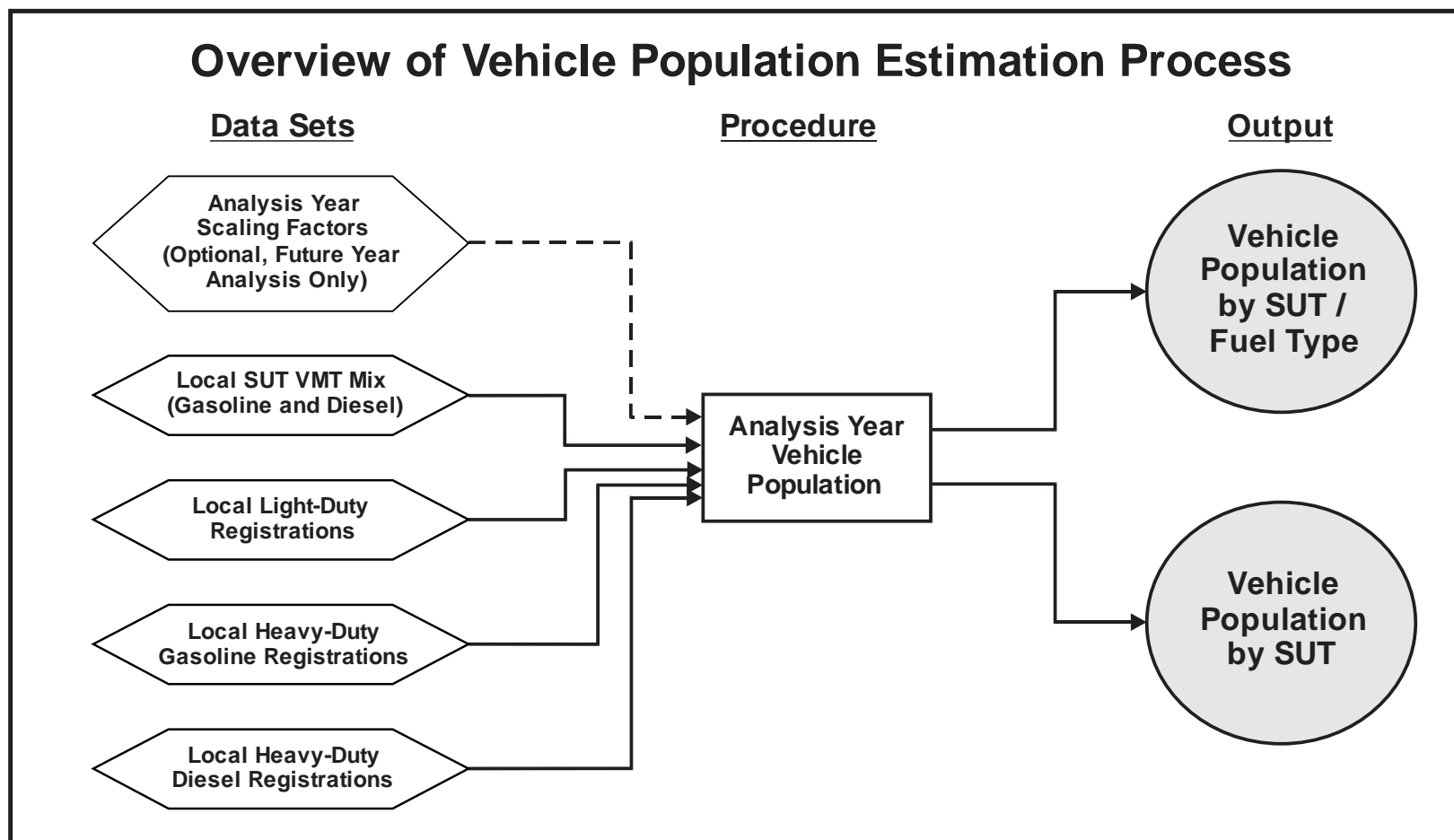
The county-level vehicle population estimates are developed using the VehPopulationBuild utility. The county-level SHP, starts, SHI, and APU hours of off-network activity are developed using the OffNetActCalc utility. Appendix A contains a description of the utilities.

Estimation of Vehicle Population

The vehicle type population estimates are needed to estimate the SHP and starts off-network activity. The vehicle population estimates are produced for each county and analysis year. The vehicle population estimates are a function of vehicle registration data (TxDMV registration data sets), population scaling factors (where applicable), and VMT mix.

For estimating vehicle populations, a historical analysis year is defined as any year where actual TxDMV registration data and HPMS VMT data (used in developing population scaling factors) exists. All other analysis years are considered future analysis years (i.e., TxDMV registration data and/or HPMS VMT data do not exist). For future analysis years, the vehicle population estimates are based on the most recent year TxDMV registration data set for which HPMS VMT data exists and analysis year population scaling factors.

The VMT mix used to estimate the vehicle population is the aggregate (i.e., all road-type categories) TxDOT district-level weekday VMT mix. The development of the VMT mix is described in more detail in the "Development of Vehicle Type VMT Mix" section. Figure 3 shows an overview of the vehicle population estimation process.



Source: Texas A&M Transportation Institute, October 2015.

Figure 3. Vehicle Population Estimation Process Overview.

Historical Vehicle Population Estimates

The county-level vehicle population estimates for a historical analysis year are calculated using the analysis year, mid-year TxDMV vehicle registrations (list vehicle registrations by model year for each county) and an assigned aggregate VMT mix (see Table 4). The vehicle population estimation process assumes that all of the non-long-haul SUT category populations for a county are represented in the county vehicle registrations data. This process also estimates the long-haul category populations as an expansion of the county registrations. There are three main steps in the vehicle population estimation process: registration data category aggregation, calculation of the vehicle type population factors, and estimation of the county-level vehicle population by vehicle type.

The first step in the vehicle estimation process is the registration data category aggregation. For each county, the analysis year vehicle registrations are aggregated into five categories. Table 6 shows these five categories.

Table 6. Registration Data Categories.

Registration Data Category	Vehicle Registration Aggregation
1	Motorcycles
2	Passenger Cars (PC)
3	Trucks <= 8.5 K gross vehicle weight rating (GVWR) (pounds)
4	Trucks > 8.5 and <= 19.5 K GVWR
5	Trucks > 19.5 K GVWR

The second step is calculating the vehicle type population factors. Using the assigned aggregate VMT mix, population factors are calculated for each vehicle type. For the non-long-haul SUT categories, the population factors are calculated by dividing the vehicle type VMT mix by the summed total of the VMT mix fractions in its associated vehicle registration data category. For example, the LCT_Diesel population factor using the VMT mix is $LCT_Diesel / (PT_Gas + PT_Diesel + LCT_Gas + LCT_Diesel)$. For the long-haul SUTs, the vehicle type population factors are calculated by taking the ratio of the long-haul and short-haul VMT mix values. For example, the SULhT_Gas population factor using SUT mix fractions is $SULhT_Gas / SUSHT_Gas$. Table 7 shows the vehicle registration aggregations and their associated MOVES SUT/fuel types.

Table 7. TxDMV Vehicle Registration Aggregations and Associated Vehicle Types for Estimating Vehicle Populations.

Vehicle Registration ¹ Aggregation	Associated Vehicle Type ²
Motorcycles	MC_Gas
Passenger Cars (PC)	PC_Gas; PC_Diesel
Trucks <= 8.5 K GVWR (pounds)	PT_Gas; PT_Diesel; LCT_Gas; LCT_Diesel
Trucks > 8.5 and <= 19.5 K GVWR	RT_Gas; RT_Diesel SUSHT_Gas; SUSHT_Diesel MH_Gas; MH_Diesel IBus_Diesel TBus_Gas; TBus_Diesel SBus_Gas; SBus_Diesel
Trucks > 19.5 K GVWR	CShT_Gas; CShT_Diesel
NA ¹	SULhT_Gas; SULhT_Diesel CLhT_Gas; CLhT_Diesel

¹ The four long-haul SUT/fuel type populations are estimated using a long-haul-to-short-haul weekday SUT VMT mix ratio applied to the short-haul SUT population estimate.

² The mid-year TxDMV county registrations data extracts are used (i.e., the three-file data set consisting of: 1 - light-duty cars, trucks, and motorcycles; 2 - heavy-duty diesel trucks; and 3 - heavy-duty gasoline trucks) for estimating the vehicle populations.

The third step is the estimation of the county-level vehicle type population. The non-long-haul vehicle type populations are estimated by applying their vehicle type population factors to the appropriate registration data category. For the CLhT_Gas type, the vehicle population was set to 0. For the remaining three long-haul SUT/fuel types (SULhT_Gas, SULhT_Diesel, and CLhT_Diesel), the vehicle populations are calculated as the product of the corresponding short-haul category vehicle population and the associated long-haul population factor (e.g., SULhT_Gas vehicle population = SUSHT_Gas vehicle population x [SULhT_Gas SUT mix fraction/ SUSHT_Gas SUT mix fraction]).

Future Vehicle Population Estimates

The process for estimating the county-level vehicle population estimates for a future analysis year is very similar to the historical vehicle population estimates except that instead of using the analysis year registration data sets, the most recent mid-year TxDMV registration data sets for which HPMS data exists are used. Using these registration data sets and the assigned VMT mix, the base vehicle type population is calculated. To estimate the future analysis year county-level vehicle populations, county-level vehicle population scaling factors are applied to the base vehicle type population. These county-level vehicle population scaling factors are calculated as the ratio of the county-level weekday VMT for the analysis year to the county-level weekday VMT for the year of the most recent mid-year TxDMV registration data (i.e., vehicle population increases linearly with VMT).

Estimation of SHP

The county-level summer weekday estimates of SHP are calculated by hour and vehicle type for each analysis year. For each hour, the county-level vehicle type SHP is calculated by taking the difference between the vehicle type total available hours minus the vehicle type SHO. Since this calculation was performed at the hourly level, the vehicle type total available hours is set equal to the vehicle type population. The SHO is calculated using the link VMT and speeds and the TxDOT district-level vehicle type VMT mixes by MOVES road-type category (see the “Development of Vehicle Type VMT Mix” section for more details).

Vehicle Type Total Available Hours

The vehicle type total available hours is typically calculated as the vehicle type population times the number of hours in the time period. Since this calculation is performed at the hourly level, the vehicle type total available hours for each analysis year is set equal to the vehicle type vehicle population for the analysis year.

Vehicle Type SHO

To calculate the VHT (or SHO) for a given link, the VMT is allocated to each vehicle type using the TxDOT district-level vehicle type VMT mixes by MOVES road-type category, which is then divided by the link speed to calculate the link vehicle type SHO. These VMT mixes are the same VMT mixes used to estimate emissions in the emissions estimation process. This SHO calculation is performed for each link in a given hour, aggregating the SHO to one value per vehicle type per hour.

Estimation of Starts

The second activity measure needed to estimate the off-network emissions using the mass per activity emissions rates are county-level weekday estimates of starts by hour and vehicle type for each analysis year. The vehicle type hourly default starts per vehicle are multiplied by the analysis year county-level vehicle type vehicle population to estimate the county-level vehicle type starts by hour.

For the hourly default starts per vehicle, the MOVES defaults are used. The MOVES activity output is used to estimate the hourly starts per vehicle for a MOVES weekday run by dividing the MOVES start output by the MOVES vehicle population output. These MOVES national default starts per vehicle do not vary by year, only by MOVES day type. For a summer weekday analysis, the MOVES national default “weekday” starts per vehicle are used.

Estimation of SHI and APU Hours

The remaining activity measures needed to estimate the off-network emissions using the mass per activity emissions rates are the hourly, county-level weekday heavy-duty diesel truck (SUT 62, fuel type 2 [CLhT_Diesel]) hotelling activity (comprised of SHI and APU hours) for each analysis year. During hotelling, the truck’s main engine is assumed to be in idling mode or its APU is in use. For each analysis year, hotelling hours activity are first estimated, and then it is allocated to the SHI and APU hours components.

The hotelling activity is based on information from a TCEQ extended idling study, which produced 2004 summer weekday extended idling estimates for each Texas county, and hotelling

activity data from MOVES. Hotelling scaling factors (by analysis year) are applied to the base 2004 summer weekday hotelling values from the study to estimate the 24-hour hotelling by analysis year. Hotelling hourly factors are then applied to allocate the 24-hour hotelling by analysis year to each hour of the day. To ensure valid hourly hotelling values are used, the hourly hotelling activity is compared to the CLhT_Diesel hourly SHP (i.e., hourly hotelling values cannot exceed the hourly SHP values). SHI and APU hours factors are then applied to the hotelling hours to produce the hourly SHI and APU hours of activity for each analysis year.

Hotelling Activity Scaling Factors

To estimate the county-level 24-hour hotelling activity by analysis year, county-level hotelling activity scaling factors are developed using the county-level 2004 summer weekday link-level VMT and speeds, the TxDOT district-level base weekday vehicle type VMT mix (by MOVES road type), the county-level analysis year weekday link-level VMT and speeds, and the TxDOT district-level analysis year vehicle type VMT mix (by MOVES road type). The 2004 summer weekday link-level VMT and speeds are developed using a process similar to the historical analysis year summer weekday link-level VMT speed estimation, except using a 2004 summer weekday VMT control total. The vehicle type VMT mixes are the same VMT mixes used to estimate emissions in the emissions estimation process (see Table 4). For the base weekday vehicle type VMT mix, the 2005 weekday vehicle type VMT mix is used.

For each link in the 2004 summer weekday link-level VMT and speeds, the link VMT is allocated to CLhT_Diesel using the base weekday vehicle type VMT mix. This VMT allocation was performed for each link and hour in the 2004 summer weekday link-level VMT and speeds, with the individual link VMT aggregated by hour to produce the CLhT_Diesel hourly and 24-hour 2004 summer weekday VMT. Using a similar allocation process, the analysis year CLhT_Diesel hourly and 24-hour VMT is calculated using the analysis year weekday link-level VMT and speeds and the analysis year vehicle type VMT mix. The county-level 24-hour hotelling activity scaling factors by analysis year are calculated by dividing the analysis year and day type CLhT_Diesel 24-hour VMT by the CLhT_Diesel 24-hour 2004 summer weekday VMT.

Hotelling Activity Hourly Factors

To allocate the analysis year weekday county-level 24-hour hotelling activity to each hour of the day, hotelling activity hourly factors are used. These hotelling activity hourly factors are calculated as the inverse of the analysis year weekday CLhT_Diesel hourly VMT fractions. The analysis year weekday CLhT_Diesel hourly VMT fractions are calculated using the hourly analysis year weekday CLhT_Diesel VMT. The hourly analysis year weekday CLhT_Diesel VMT is converted to hourly fractions. The inverse of these hourly VMT fractions are calculated and the inverse for each hour is divided by the sum of the inverse hourly VMT fractions across all hours to calculate the county-level analysis year weekday hotelling activity hourly factors.

County-Level CLhT_Diesel Hotelling Activity by Hour Estimation

The initial analysis year weekday CLhT_Diesel hotelling activity by hour is calculated by multiplying the 24-hour 2004 summer weekday hotelling hours by the analysis year hotelling activity scaling factor and by the analysis year hotelling activity hourly factors. For each hour, the initial analysis year weekday hotelling activity is then compared to the analysis year weekday CLhT_Diesel SHP to estimate the final analysis year weekday hotelling activity by hour. If the

initial analysis year weekday hotelling activity value is greater than the analysis year weekday SHP value, then the final analysis year weekday hotelling activity for that hour is set to the analysis year weekday CLhT_Diesel SHP value. Otherwise, the final analysis year weekday hotelling activity for that hour is set to the base analysis year weekday hotelling activity value. All calculations (scaling factors, hotelling activity hourly factors, and hotelling activity by hour calculations) are performed by county and analysis year (i.e., eight hotelling activity scaling factors are calculated per analysis year).

County-Level CLhT_Diesel SHI and APU Hours Estimation

The hourly county-level hotelling activity for each analysis year is then allocated to SHI and APU hours activity components using aggregate extended idle mode and APU mode fractions. For each hour, the analysis year hotelling activity is multiplied by the SHI fraction to calculate the analysis year hourly SHI activity and by the APU fraction to calculate the analysis year hourly APU activity.

The aggregate SHI and the APU fractions are estimated using model year travel fractions (based on source type age distribution and relative mileage accumulation rates used in the MOVES runs) and the MOVES default hotelling activity distribution (i.e., a bi-modal distribution of 1.0 SHI prior to the 2010 model year and a 0.7/0.3 SHI/APU activity allocation for 2010 and later model years). The associated travel fractions are applied to the appropriate extended idle and APU operating mode fractions (of the hotelling operating mode distribution) by model year and summed within each mode to estimate the aggregate (across model years) individual SHI and APU fractions (which sum to 1.0).

ESTIMATION OF EMISSIONS FACTORS

TTI develops the summer weekday emissions factors consistent with TTI's MOVES detailed link-based emissions estimation method based on the TTI's *Updated Inventory Methods for MOVES*⁴ and the EPA's MOVES inventory development *Technical Guidance*⁵ and *User's Guide*.⁶ TTI's MOVES data post-processing utilities, RatesCalc and RatesAdj used to produce databases of emissions rate look-up tables for input to the emissions calculations, are also summarized in Appendix A.

The general process involves set up of MOVES emissions rate mode runs to produce rates, emissions, and activity data in one MOVES output database, needed for the development of on-road mobile source emissions rates. The TTI rates look-up table calculator for on-road emissions rates (EmsCalc), is then run to produce emissions rate look-up database tables from the MOVES data. The Rate adjustment utility (RatesAdj) is then run to produce the final rate look-up tables by filtering out only the pollutants needed in the inventories, and making adjustments, where required.

The inventory method requires all rates be in terms of mass/activity (as opposed to the off-network rates of mass/vehicle, which is the only output option available for the off-network

⁴ *Update of On-Road Inventory Development Methodologies for MOVES2014*, TTI, December 2014.

⁵ *MOVES2014 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity*, EPA, January 2015.

⁶ *Motor Vehicle Emission Simulator (MOVES) User Guide for MOVES1014*, EPA, July 2014.

evaporative emissions rates by MOVES) for the external emissions calculations. Table 8 shows the emissions rates types and associated activity factors.

Table 8. Emission Rates by Process and Activity Factor.

Emission Processes	Activity¹	Emissions Factor²
Running Exhaust Crankcase Running Exhaust Brake Wear Tire Wear	VMT	mass/mile
Evaporative Permeation Evaporative Fuel Vapor Venting Evaporative Fuel Leaks	VMT	mass/mile
	SHP	mass/shp
Start Exhaust Crankcase Start Exhaust	starts	mass/start
Auxiliary Power Exhaust	APU hours	mass/APU hour
Extended Idle Exhaust Crankcase Extended Idle Exhaust	SHI	mass/shi

¹ SHI and APU hours are for combination long-haul trucks only.

² All of the rates are directly available from MOVES, except mass/shp, which is produced by the TTI RatesCalc utility using MOVES rates mode input and output data.

MOVES Inputs, Outputs and Post-Processing

The MOVES model is equipped with default modeling values for the range of conditions that affect emissions factors. MOVES defaults may be replaced by alternate input data sets that better reflect local scenario conditions. Where available and consistent with the methodology, local data is used to replace the MOVES defaults via the MOVES Run Specification input file (RunSpec or MRS) and MOVES CDB (county input database), which provide the data for each local scenario model run. Inputs are developed to produce emissions factors reflecting local conditions including area summer period average weather conditions, summer fuel properties, vehicle fleet characteristics (e.g., age), and emissions control programs. In the case of the activity input data to MOVES, the MOVES defaults are generally used (default activity is normalized in the emissions rates, and the emissions rates are later multiplied by the local activity estimates to calculate emissions external to MOVES).

There is one RunSpec required per county and analysis year, and a corresponding number of CDBs, output databases, RatesCalc output databases, and RatesAdj final rate output databases, when necessary (i.e., one output database per run). RatesCalc produces the entire set of rates in terms of mass per activity, including those rates that must be calculated. When necessary, RatesAdj produces the final rates by performing emission rate adjustments, such as oxides of nitrogen (NO_x) TxLED effect adjustments to diesel vehicle NO_x rates, and extracting and storing the rates for the inventoried pollutants in a separate, smaller database for input to the emissions runs. The RatesCalc and RatesAdj utilities used to produce the emissions rates from the MOVES data are described in Appendix A.

Summary of Control Programs Modeled

Table 9 summarizes the control measures and modeling approaches (e.g., MOVES model defaults versus alternative local inputs, or post-processing of MOVES output) that may be included, depending upon the applicability to specific county.

Table 9. Emissions Control Strategies and Modeling Approaches.

Individual Control Measures	Approach
Federal Motor Vehicle Control Program Standards	MOVES defaults.
Federal Heavy-Duty Diesel Engines Rebuild and 2004 Pull-Ahead Programs to Mitigate NO _x Off-Cycle Effects	MOVES defaults.
Reformulated Gasoline (RFG)	MOVES model – region-specific RFG fuel formulation inputs, based on survey data, with average sulfur content set for consistency with the Tier 3 sulfur standard when applicable.
Texas Low-Emission Diesel (TxLED)	Sulfur content – MOVES model and/or survey data. Post-processing of diesel vehicle NO _x rates – diesel vehicle NO _x emissions factors for all counties are adjusted using evaluation year and SUT-specific average NO _x reduction factors produced following TCEQ’s procedure.
Inspection and Maintenance (I/M) Program	Local input to MOVES – For affected counties, TTI uses available MOVES I/M parameters for I/M vehicles (in terms of MOVES I/M “teststandards” and associated “imfactors”), consistent with current program description and latest I/M modeling protocol, with MOVES2014a updates where needed.

MOVES Emissions Factor Aggregation Levels

The MOVES model produces results at different aggregation levels that may be specified in the MRS. The detailed, hourly, link-based inventory method requires MOVES weekday day type emissions rates at the following MOVES output detail level:

- Up to 13 source types (i.e., vehicle types);
- Up to six fuel types;
- Up to five road types (four actual MOVES road categories and “off-network”);
- Each of the 24 hours in a day;
- 16 speed bins (only included in miles-based rate tables);
- Up to 156 pollutants; and
- Up to 14 emission processes.

The vehicle fleet is modeled as powered only by the predominant on-road fuels of gasoline and diesel (alternate fuels considered *de minimis*). The five road type categories in MOVES are Off-Network (not actually a road type, this category is for parked vehicle activity), Rural Restricted Access, Rural Unrestricted Access, Urban Restricted Access, and Urban Unrestricted Access.⁷ The rates for each of the actual four MOVES road types are indexed by the 16 MOVES speed bin average speeds: 2.5, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, and 75 mph.

MOVES Run Specifications

The MRS defines the place, time, road categories, vehicle and fuel types, pollutants and emissions processes, and the overall scale and level of output detail for the modeling scenario. TTI creates an MRS for one county scenario (analysis year summer weekday) using the MOVES graphical user interface (GUI), which is then converted to a template and used as a base MRS from which to build the MRSs for the analysis.

Table 10 describes the MRS selections TTI uses, with further details on the selections provided after the table.

⁷ The “separate ramps” feature intended for MOVES2014 October Release was not activated for emissions rates mode, but is expected to be available for emissions rates output in the next release of MOVES.

Table 10. RunSpec Selections by MOVES GUI Navigation Panel.

Navigation Panel	Detail Panel	Selection		
Scale ¹	Model; Domain/Scale; Calculation Type	On-Road; County; Emissions Rates		
Time Spans ¹	Time Aggregation Level; Years – Months – Days – Hours	Hour; Analysis Year ¹ - July - Weekday - All		
Geographic Bounds ¹	Region; Selections; Domain Input Database	Zone and Link; <COUNTY>; ¹ <COUNTY INPUT DATABASE (CDB) NAME> ¹		
On-Road Vehicle Equipment	SUT/Fuel Combinations	SUT	Gasoline	Diesel
		Motorcycle	X	-
		Passenger Car	X	X
		Passenger Truck	X	X
		Light Commercial Truck	X	X
		Intercity Bus	-	X
		Transit Bus	-	X
		School Bus	X	X
		Refuse Truck	X	X
		Single Unit Short-Haul Truck	X	X
		Single Unit Long-Haul Truck	X	X
		Motor Home	X	X
		Combination Short-Haul Truck	X	X
Combination Long-Haul Truck	-	X		
Road Type	Selected Road Types	Off-Network – Rural Restricted Access – Rural Unrestricted Access – Urban Restricted Access – Urban Unrestricted Access		
Pollutants and Processes ²	VOC; CO; NO _x ; Atmospheric CO ₂ ; Other Pollutants as Required	Dependent on pollutant: Running Exhaust, Start Exhaust, Extended Idle Exhaust, Auxiliary Power Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust, Crankcase Extended Idle Exhaust, Evap Permeation, Fuel Vapor Venting, Fuel Leaks, Brakewear, Tirewear		
Manage Input Data Sets	Additional Input Database Selections	None		
Strategies	Rate-of-Progress	Not Applicable		
General Output	Output Database; Units; Activity	<MOVES OUTPUT DATABASE NAME>; ¹ Pounds, KiloJoules, Miles; Hotelling Hours, Population, Starts (not adjustable, pre-selected)		
Output Emissions Detail	Always; For All Vehicles/Equipment; On Road	Time: Hour – Location: Link – Pollutant; Fuel Type, Emissions Process; Source Use Type		
Advanced Performance Measures	Aggregation and Data Handling	All check boxes are to be “un-checked”		

¹ County scale allows one county and year per run.

² Chained pollutants require other pollutants (not listed in the table) to be selected (e.g., VOC requires Total Gaseous Hydrocarbons [THC] and Non-Methane Hydrocarbons: Carbon dioxide (CO₂) requires Total Energy Consumption [TEC]).

Scale, Time Spans, and Geographic Bounds

The MOVES Domain/Scale “County” is selected, along with the MOVES Calculation Type “Emissions Rates” for MOVES to produce the emissions rates with speed bin indexing, as needed for the detailed link-based emissions estimation process.

The Time Spans parameters are specified to provide the most detail available, which is the hourly aggregation level, for all hours of the day, for the selected year, month, and day type. One analysis year per run is selected, as MOVES allows only one “Years” selection for the County Domain Scale. For TTI’s MOVES-based link emissions estimation process, which is for a single day, one “Months” (July) and one “Days” (Weekdays) selection is made.

Under Geographic Bounds for the County Domain Scale, only one county may be selected. The local CDB containing the calendar year scenario-specific input data for the county is specified as the County Domain Input Database, and under Region, “Zone & Link” is selected as required for the emissions rates calculation type. With these required set-ups, one county, one year, one day type, and 16 (speed bin) average speeds are modeled per run.

On-Road Vehicle Equipment and Road Type

The local VMT mixes define the SUT/fuel type combinations included in the MOVES runs and specifies the vehicle fleet as the 22 gasoline and diesel SUTs designated as “on-road vehicle equipment” selections in Table 10. These SUT/fuel type combinations are chosen in all the MOVES RunSpecs. Note that, as required, the MOVES default fuel engine fractions (discussed later) are also replaced with local input data consistent with the SUT/fuel type selections shown in Table 10.

All five MOVES road type categories are selected (the “provide separate ramps output” box is not active when using emissions rates mode).

Pollutants and Processes

In addition to the required pollutants within the scope of the inventory, MOVES requires that additional pollutants be selected for particular “chained” pollutants (i.e., pollutants that are calculated as a function of another MOVES pollutant). All of the associated processes available for the selected pollutants are included.

Manage Input Data Sets and Strategies

The Manage Input Datasets feature allows alternate inputs other than those included in the CDB. No additional inputs are included via the Manage Input Datasets panel.

The Strategies feature is for modeling an alternate control program option, which is not applicable to this type of inventory analysis.

Output

The output units are pounds, kilojoules, and miles. The activity categories are pre-set by MOVES (and not adjustable) for inclusion in the output database. The output detail level is by hour, link (e.g., for MOVES rates mode, county/road type/speed bin combination), pollutant, process, SUT, and fuel type.

MOVES County Input Databases

The locality-specific input data for the county scale runs are entered through the CDB.

TTI has developed procedures to accommodate building and checking CDBs for large scale emissions inventory estimation projects. The basic procedure is to write a MySQL script to produce one county scenario CDB and convert it to a template from which all of the CDB scripts are built. The MySQL scripts are then run in batch mode to produce all CDBs for the analysis.

Data for populating the CDBs are first prepared in the form of text files and/or MySQL databases (e.g., for local fuels and weather data), and some values are provided directly in the CDB builder MySQL script. Any default data used is selected from the latest MOVES default database, MOVESDB20151028 (e.g., for default activity data). After running the scripts to produce the CDBs, a CDB checker utility written by TTI is run to verify that all CDB tables are built and populated as intended.

Table 11 provides an outline and brief description of the CDBs, followed by discussion of the development of the local data and the defaults contained therein.

Table 11. CDB Input Tables.

MOVES Input Table	Data Category	Notes
year	Time	Designates analysis year as a base year (base year means that local activity inputs are supplied rather than forecast by the model).
state	Geography	Identifies the state (Texas) for the analysis.
county	Geography/ Meteorology	Identifies county of analysis, local altitude, and barometric pressure.
zonemonthhour	Meteorology	Local, hourly temperature, and relative humidity for the county.
roadtype ¹	Activity	Lists the MOVES road types and associated ramp activity fractions. Road type ramp fractions are set to 0.
hpmsvtypeyear ²	Activity	Use MOVES default national annual VMT by HPMS vehicle type.
roadtypedistribution ²		Use MOVES default road type VMT fractions.
monthvmtfraction ²		Use MOVES default month VMT fractions.
dayvmtfraction ²		Use MOVES default day VMT fractions.
hourvmtfraction ²		Use MOVES default hour VMT fractions.
avgspeeddistribution ²		Use MOVES default average speed distributions.
sourcetypeyear ²	Fleet	Use MOVES default national SUT populations.
sourcetypeage-distribution	Fleet	TTI estimates local SUT age fractions using TxDOT/TxDMV vehicle registration data and MOVES defaults, as needed. For historical years, TTI uses the mid-year registration data for the analysis year, and uses the latest available mid-year registration data for future years.
avft	Fleet	TTI estimates SUT fuel fractions using TxDOT/TxDMV vehicle registration data and defaults where needed. Local data sets are consistent with sourcetypeagedistribution tables.
zone	Activity	Start, idle, and SHP zone allocation factors. County = zone, and all factors are set to 1.0 (required for county scale analyses).
zoneroadtype	Activity	SHO zone/roadtype allocation factors. County = zone, and all factors are set to 1.0 (required for county scale analyses).
fuelsupply	Fuel	The fuel supply, or market shares, reflect one gasoline and one diesel fuel formulation for each county and year.
fuelformulation	Fuel	TTI uses a combination of local data, survey data, and Tier 3 Rule to develop these inputs, depending upon the analysis year.
imcoverage	I/M	TTI prepares locality-specific set-ups to represent I/M program design/description for each county and analysis year based on current I/M rules, prior modeling set-ups, and available MOVES I/M parameters (in terms of MOVES I/M “teststandards” and associated “imfactors”) for the I/M vehicles. Regulatory class adjustments are updated consistent with <i>MOVES Technical Guidance</i> , EPA, November 2015).
countyyear	Stage II	Table is included in the CDB as standard procedure, but not applicable to this type of analysis, and with no effect on resulting emissions inventories.

¹ MOVES will not produce “ramp road type” rates in a single run with all road types. To calculate emissions for certain travel model links coded as ramps, MOVES Unrestricted Access road type emissions rates are used.

² Use of a default set of activity and population inputs for all MOVES runs is basic to the inventory method, e.g., MOVES default activity is normalized in the calculated emissions rates for pertinent emissions processes, and actual local activity estimates are used in the external emissions calculations.

Year, State, and County Inputs to MOVES

The year, state, and county tables are populated with data identifying the year, state, and county of the run.

The yearID field of the “year” table is populated with the analysis year value, and the year is set as a base year (to specify that particular user-input fleet and activity data are to be used, rather than forecast by MOVES during the model runs). As part of designating the appropriate fuel supply for the modeling scenario, the fueleyearID in the year table is also set to the analysis year.

StateID “48” (Texas) was inserted in the state table. In addition to identifying the county of analysis, the county table contains barometric pressure and altitude information (discussed further with other meteorological inputs). The county data are selected from a prepared local “meteorology” database containing tables of weather data records (i.e., “county” and “zonemonthhour” tables) for the analysis.

Roadtype Inputs to MOVES

Currently the MOVES model contains “ramp” emissions rates, but not an (activated) individual road type for separate ramps output (when using MOVES rates mode). In the roadtype table, MOVES provides a field “rampFraction” for including a fraction of estimated ramp activity as a fraction of SHO on each of the MOVES road types. The MOVES default roadtype table data are used, except the ramp fractions are set to zero (i.e., 100 percent of activity on each MOVES road type is based on the road type drive cycles assigned to that road type by MOVES, exclusive of ramp activity).

Activity and Vehicle Population Inputs to MOVES

The activity and vehicle population input parameters under the methodology use the MOVES defaults. The tables are: hpmsvtypeyear, roadtypedistribution, monthvmtfraction, dayvmtfraction, hourvmtfraction, avgspeeddistribution, and sourcetypeyear. Data for all of these tables are selected and inserted from the MOVES default database.

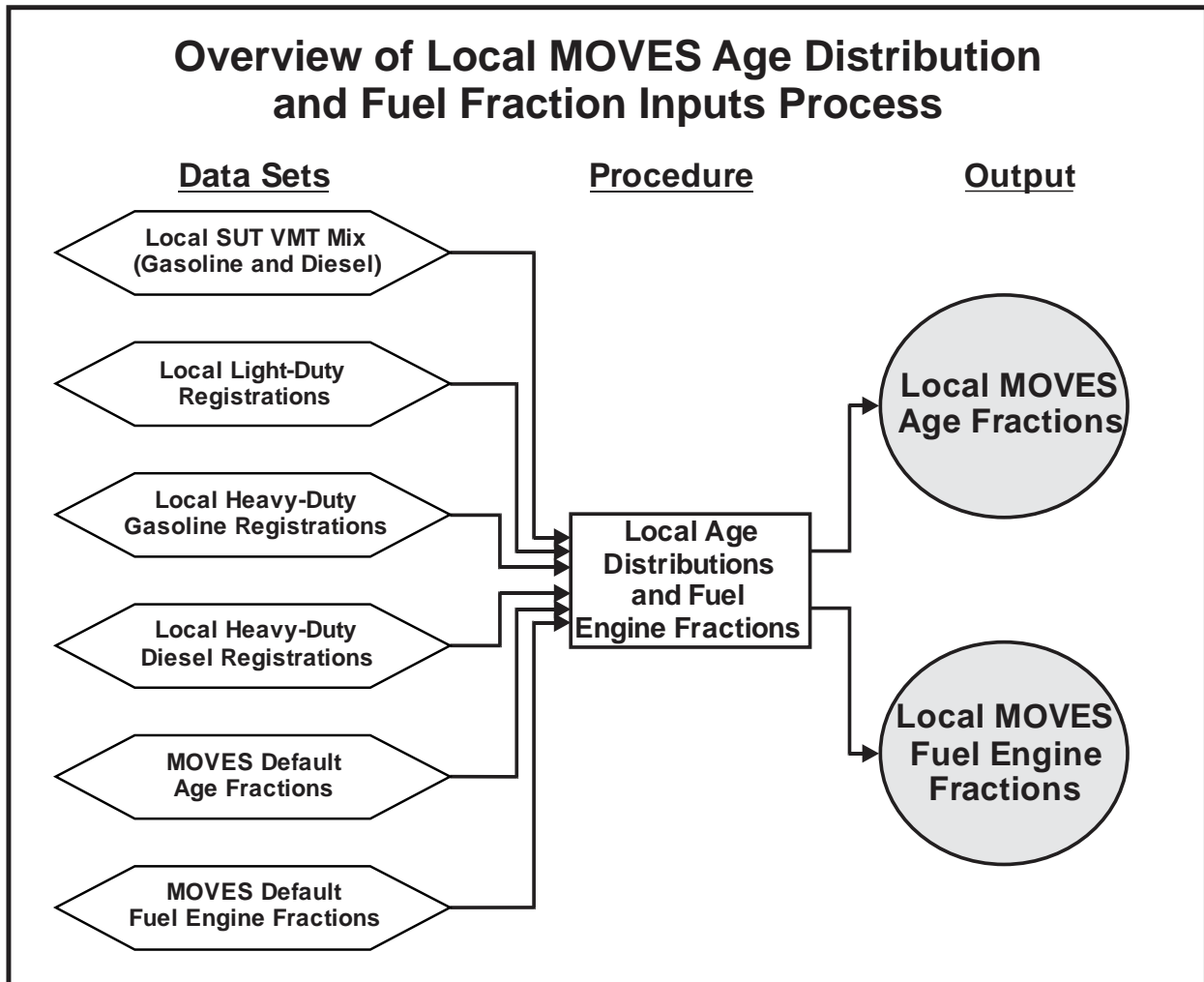
The zone and zoneroadtype tables contain zonal sub-allocation activity factors. For county scale analyses, county is equal to zone, therefore these allocation factors are set to 1.0.

Age Distributions and Fuel Engine Fractions Inputs to MOVES

The locality-specific vehicle age and fuel type fractions by model year inputs to MOVES consist of county-level age distributions and statewide gasoline and diesel fractions (termed fuel engine fractions in MOVES). The age distributions and fuel engine fractions inputs are calculated and written to text files in preparation for loading the data into the appropriate CDB input tables: the sourcetypeagedistribution table for vehicle age distributions, and the AVFT table for fuel engine fractions. The MOVESfleetInputBuild utility is used to produce these fleet inputs to MOVES in the required formats (see utility description in Appendix A), and MySQL scripts are used to populate the CDB input tables.

The age distributions and fuel engine fractions are based on TxDMV mid-year county registrations data and MOVES model defaults, where needed. The fuel engine fractions are

developed consistent with the local VMT mix estimate (e.g., no compressed natural gas (CNG) vehicles, no E-85 fuel type, and no gasoline transit buses in the VMT mix are reflected in the local fuel engine fractions estimates). Locality-specific SUT age distributions are produced based on the TxDMV county vehicle registration category aggregations, consistent with the vehicle registration category aggregations of the VMT mix (see Appendix A). Figure 4 shows an overview of the age distribution and fuel engine fractions development process.



Source: Texas A&M Transportation Institute, October 2015.

Figure 4. Overview of the Age Distribution and Fuel Engine Fractions Development Process.

Table 12 summarizes the data sources and aggregation levels used to estimate the county source-type age distributions and fuel engine fractions.

Table 12. Sources and Aggregations for SUT Age Distributions and Fuel Engine Fractions.

SUT Name	SUT ID	TxDMV Category ¹ Aggregations for Age Distributions and Fuel Engine Fractions	Geographic Aggregation for Age Distributions	Geographic Aggregation for Fuel Engine Fractions ²
Motorcycle	11	Motorcycles	County	NA – 100 percent gas, no fuel engine fractions
Passenger Car	21	Passenger	County	MOVES default ²
Passenger Truck	31	Total Trucks<=8500	County	MOVES default ²
Light Commercial Truck	32	Total Trucks<=8500	County	MOVES default ²
Single Unit Short-Haul Truck	52	>8500+ >10000+ >14000+>16000	Region	Texas statewide
Single Unit Long-Haul Truck	53	>8500+ >10000+ >14000+>16000	Texas statewide	Texas statewide
Refuse Truck	51	MOVES default		
Motor Home	54			
Intercity Bus	41			
Transit Bus ²	42			
School Bus	43			
Combination Short-Haul Truck	61	>19500+ >26000+ >33000+ >60000	Region	Texas statewide
Combination Long-Haul Truck	62	>19500+ >26000+ >33000+ >60000	Texas statewide	NA – 100 percent diesel, no fuel engine fractions

¹ TxDOT/TxDMV mid-year (analysis year for historical years and latest available for future years where data is not available) county vehicle registrations data (i.e., three-file data set: composite fuel light-duty categories; heavy-duty gasoline by eight weight categories; and heavy-duty diesel by eight weight categories) are used for developing local inputs (weights are GVWR in units of lbs.). The MOVES2014a model default age distributions are from the MOVESDB20151028 database.

² Consistent with the local vehicle type VMT mix, MOVES fuel engine fractions for light-duty categories are revised to exclude E-85, and for transit buses are revised to exclude CNG and gasoline components. MOVES default fuel engine fractions are taken from the MOVESDB20151028 sample vehicle population table.

Local Meteorological (County and Zonemonthhour Table) Inputs to MOVES

The meteorological inputs are input via the “county” (barometric pressure) and “zonemonthhour” (temperature and relative humidity) tables. These input data are developed from local hourly temperature and relative humidity, and 24-hour barometric pressure averages. Altitude, also an input of the county table, is set to “low” for all counties.

Fuels Inputs to MOVES

The local fuels inputs to MOVES are input in the CDB fuelsupply and fuelformulation tables. The summer season fuel supply for each county and year consist of one average RFG and one average diesel fuel formulation (and therefore gasoline and diesel fuel supply market share values are 1.0 for each). The data sources for these fuel formulations are largely local survey data, although for average sulfur content, default values reflecting regulatory standards are used as the expected values for certain future years. TTI prepares fuels input data in spreadsheets, saves them to text files, and imports these local fuels inputs to storage database tables (fuelformulation and fuelsupply), using IDs for the local fuel formulations outside the range of MOVES default fuel formulation IDs. County-fuel scenario data are selected from storage and inserted into the CDB fuelsupply and fuelformulation tables.

Local I/M Inputs to MOVES

This discussion covers the current 17 Texas I/M counties. An I/M program is required in counties of the Austin, Dallas/Ft. Worth (DFW), El Paso, and Houston areas (the notes in Table 13 provide a list of the counties).

In general, MOVES produces a local I/M program effect as an adjustment to the model's reference I/M program effect (i.e., the "standard I/M difference" in MOVES base emissions rates, which are specific to vehicle regulatory class categories of which the higher level source types are composed). MOVES contains a large set of "I/M factors" by source type (in the imfactor table) computed specifically for adjusting the MOVES standard I/M difference in order to reflect the effects of various, local I/M program design alternatives. To model a local I/M program design, it must be defined using MOVES I/M coverage parameters by source type, entered in the MOVES imcoverage table. The appropriate MOVES I/M factors for modeling a local I/M program are designated in a model run by the local program data in the imcoverage table.

MOVES adjusts emissions (hydrocarbons [HC], carbon monoxide [CO], and NO_x) at the source-type level to incorporate the benefits of the local I/M program design defined using the MOVES I/M coverage table parameters. TTI previously produced a comprehensive set of MOVES imcoverage records for Texas I/M counties for use instead of MOVES defaults. TTI has updated this Texas local imcoverage database to include a small change in one regulatory class coverage adjustment.⁸

The imcoverage parameters (by field header) are:

- polProcessID (pollutant and emissions process affected by the program);
- stateID (state subject to the I/M program);
- countyID (county FIPS);

⁸ TTI compared I/M data (e.g., emissionratebyage standard I/M difference; imfactors; regulatory class coverage adjustments) between MOVES 2014a and 2014 to determine if changes called for updating local imcoverage parameters. The assessment found only a minor difference in one regulatory class coverage adjustment that warranted updating, the light commercial truck imcoverage compliancefactor value. (For further details, see Table 13 notes.)

- yearID (year administered);
- sourceTypeID (source type affected);
- fuelTypeID (fuel type for the program);
- IMProgramID (arbitrary ID number specific to a local program);
- begModelYearID (first model year included);
- endModelYearID (last model year included);
- inspectFreq (inspection frequency for the program);
- testStandardsID (I/M test type);
- useIMyn (a Y/N [yes/no] switch that specifies whether or not to use the record); and
- complianceFactor (an adjustment factor reducing the I/M effects for compliance rate, waiver rates, regulatory class coverage adjustments, or other adjustments, if needed).

To use the local imcoverage inputs, both the MOVES default imcoverage records (flagged for non-use) and local imcoverage records (flagged for use) are required in each scenario CDB.

Data Sources – TTI produces the local I/M coverage input parameters to represent Texas I/M program designs as specified in the Texas I/M State Implementation Plan (SIP) and Texas rules. The I/M program requires annual emissions testing of gasoline vehicles within a 2-through-24 year vehicle age coverage window (motorcycles, military tactical vehicles, diesel-powered vehicles, and antique vehicles are excluded). A gas cap integrity test is required on all these vehicles, and depending on the model year, gross vehicle weight (GVW) (threshold of 8,500 GVW separating light-duty and heavy-duty class), and I/M area, current vehicle emissions testing may use On-Board Diagnostics (OBD) tests, the Acceleration Simulation Mode (ASM-2) test, or the Two-Speed Idle (TSI) test. Table 13 and the associated notes describe MOVES imcoverage records developed by TTI for the years available in MOVES applicable to each Texas I/M county. For additional Texas I/M program details, see the current I/M SIP and/or pertinent Texas Administrative Code.⁹

Local I/M Coverage Input Data Development Approach – Following the general approach used to build the Texas imcoverage tables:

- Identified MOVES I/M test standards applicable to Texas I/M counties in consultation with TCEQ (see Table 22, column 5);
- Queried the MOVES database to determine the extent to which MOVES provides I/M effects corresponding to Texas I/M Programs (i.e., local I/M test frequency, fuel type, and test types [test standards]). From the result, listed the SUTs, test standards, pollutant and emissions process combinations with I/M effects in MOVES (i.e., with non-zero MOVES I/M factors and corresponding base emissions rates with non-zero standard I/M differences);

⁹ *Revision to the State Implementation Plan Mobile Source Strategies, Inspection and Maintenance State Implementation Plan Revision*, TCEQ, adoption February 12, 2014.

- Categorized counties and years in groups under the same MOVES test standards; and
- Assigned MOVES I/M Program IDs such that: 1) all MOVES default I/M Program IDs are excluded; and 2) for each year ID, each I/M Program ID represented a unique combination of test standard, test frequency, begin model year, and end model year.

Table 13. MOVES I/M Coverage Inputs for Texas Annual Inspections of Gasoline Vehicles, All Affected Counties/Years.

YearID ¹	begModel YearID ²	endModel YearID ²	testStandardsID ³	Sourcetypeid ⁴
Dallas, Tarrant, El Paso				21 (PC – Passenger Car) 31 (PT – Passenger Truck) 32 (LCT – Light Commercial Truck)
1990	1975	1990	11 (Unloaded Idle)	
Harris, Dallas, Tarrant, El Paso				
1999 through 2001	X	Y	12 (2500 RPM/Idle)	
	X	Y	41 (Evp Cap)	
El Paso				
2002 through 2006	X	Y	12 (2500 RPM/Idle)	
	X	Y	41 (Evp Cap)	
1) Harris, Dallas, Tarrant, Collin, Denton 2) Brazoria, Fort Bend, Galveston, Montgomery, Ellis, Johnson, Kaufman, Parker, Rockwall				
1) 2002 through 2019 2) 2003 through 2019	X	1995	23 (A2525/5015 Phase)	
	X	1995	41 (Evp Cap)	
	1996	Y	51 (Exh OBD)	
	1996	Y	45 (Evp Cap, OBD)	
1) Travis, Williamson; 2) El Paso				
1) 2006 through 2019 2) 2007 through 2019	X	1995	12 (2500 RPM/Idle)	
	X	1995	41 (Evp Cap)	
	1996	Y	51 (Exh OBD)	
	1996	Y	45 (Evp Cap, OBD)	
All 17 I/M Counties¹				
2020 through 2050	X	Y	51 (Exh OBD)	
	X	Y	45 (Evp Cap, OBD)	

¹ Start date: El Paso - 1/1987; Dallas, Tarrant - 4/1990; Harris - 1/1997; Collin, Denton - 5/2002; Ellis, Johnson, Kaufman, Parker, Rockwall, Brazoria, Fort Bend, Galveston, Montgomery - 5/2003; and Travis, Williamson - 9/2005.

² begmodelyearID (X) and endmodelyearID (Y) define the range of model years covered – where represented by “X” and “Y,” respectively, are calculated as YearID – 24, and YearID – 2.

³ The model processes/pollutants affected are start and running exhaust HC, CO, NO_x, and tank vapor venting HC.

⁴ Compliancefactor values by source type, generally common across areas (PC – 93.12 percent; PT – 91.26 percent; LCT – 85.67 percent), are calculated as (compliance rate) x (1.0 - waiver rate) x (regulatory class coverage adjustment) (Section 4.10.6, *MOVES Technical Guidance*, EPA, November 2015). Texas modeling protocol compliance and waiver rates are 96 percent and 3 percent. Regulatory class adjustments are PC – 100 percent, PT – 98 percent, and, LCT – 92 percent (*MOVES Technical Guidance*, Appendix A). Use of these PT and LCT source type regulatory class adjustments provide a conservative result in that the excluded portions of PT (2 percent) and LCT (8 percent), attributable to regulatory class ID 40 (Class 2b Trucks with 2 Axles and 4 Tires [8,500 lbs. < GVWR <= 10,000 lbs.], or “LHD <= 10k”), exclude a small potential evaporative gas cap effect available in MOVES for LHD<= 10k.

Checks and Runs

After completing the input data preparation, the CDBs are checked to verify that all 20 tables are in the appropriate CDBs and the tables are populated with data as intended. The MOVES RunSpecs are executed in batches using the MOVES commandline tool. After completion, TTI verifies that the MOVES runs are error free (i.e., checks all run log text files for errors and warnings).

Post-Processing Runs

Each MOVES output database is post-processed using a two-step process – for each county and year, an interim RatesCalc rate database is produced, followed by the final rates RatesAdj database containing the emissions rate tables for input to the emissions inventory calculations. The following post-processing steps are performed on each of the MOVES output databases. See the utility descriptions in Appendix A for more information.

- **Interim Rates Databases:** Using RatesCalc, the mass/SHP off-network evaporative process rates are calculated using data from the CDB, the MOVES default database, and the MOVES rateperprofile and ratepervehicle emissions rate output. The utility also copies the mass/mile, mass/start, mass/hour rates along with the units into emissions rate tables. This utility does not perform any unit conversions, and excludes total energy and refueling processes. It creates an output database containing the rates tables input to the RatesAdj utility. In addition to a table containing the run information and one with the activity data, there are four emissions rate look-up tables produced for each scenario: ttirateperdistance, ttirateperstart, ttirateperhour (for extended idle and auxiliary power exhaust), and ttiratepershp.
- **Final Rate Databases:** Using RatesAdj, TTI produces the final emissions rates for input to the EmsCalc emissions calculator. RatesAdj extracts emissions rates from the RatesCalc rate tables for only those pollutants needed in the emissions calculations, and applies emissions rate adjustments such as the TxLED adjustments to the diesel vehicle NO_x emissions rates for all counties and years. The RatesAdj output databases, one for each county and year created for input to the emissions calculations, contain a ratesadjrun table of utility execution information, and the four emissions rate tables: ttirateperdistance, ttirateperstart, ttirateperhour, and ttiratepershp.

See Appendix A for more information on the TTI MOVES on-road rates development utilities.

EMISSIONS CALCULATIONS

TTI calculates hourly, summer weekday, link-based emissions inventories by county for each year using the EmsCalc utility. Emissions calculations fall into two categories: VMT-based and off-network. The VMT-based emissions calculations use the roadway-based rates and the TDM-based VMT and speeds to estimate emissions at the TDM network link (or roadway segment) level. The off-network emissions calculations use off-network rates and off-network activity (SHP, starts, SHI, and APU hours) to estimate emissions at the county level.

Hourly Link-Based Emissions Calculations

The county, analysis year, summer weekday, hourly emissions are calculated with the EmsCalc utility using the following major inputs:

- Vehicle type VMT mix – TxDOT district-level, weekday, by MOVES roadway type for four time-of-day periods;
- Time period designation – the four VMT mix time periods to hour-of-day associations;
- Roadway-based activity – link (and intrazonal link)-specific, hourly, directional, operational VMT and speed estimates as developed by the TRANSVMT utility to include: A-node, B-node, county number, TDM road type (functional class) code, link length, congested (operational) speed, VMT, and TDM area type code;
- Roadway-based emissions factors – MOVES-based, county level by pollutant, process, hour, average speed, MOVES road type, SUT, and fuel type;
- Off-network activity – county, hourly SHP, starts, SHI, and APU hours by vehicle type;
- Off-network (parked vehicle) emissions factors – MOVES-based, county level by pollutant, process, hour, SUT, and fuel type; and
- TDM road type designations – TDM road type and area type codes to MOVES road type codes (and to VMT mix road type, and to rates road type codes).

The VMT-based emissions are calculated for each hour using the TxDOT district-level vehicle type VMT mix with time period-to-hour designations, the TDM link and intrazonal link VMT and speeds estimates, the MOVES-based “on-network” emissions factors, and the TDM road type/area type to MOVES road types designations. For each link, the link is assigned a MOVES road type (and VMT mix road type and rates road type based on the link’s road type and area type. The link VMT is then distributed to each vehicle type using the appropriate VMT mix, based on the link’s designated VMT mix road type, its associated TxDOT district, and time-of-day period to hour-of-day designation.

The emissions factors for each vehicle type for each hour are selected based on the link’s designated rates road type code (same as MOVES road type code) and the link speed. For link speeds falling between MOVES speed bin average speeds, emissions factors are interpolated from bounding speeds. For link speeds falling outside of the MOVES speed range (less than 2.5 mph and greater than 75 mph), the emissions factors for the associated bounding speeds are used. For each pollutant and process, the mass/mile rates are multiplied by the link VMT producing the link-level emissions estimates for each vehicle type.

The off-network emissions are calculated for each hour using the hourly MOVES-based off-network emissions factors by vehicle type and the county-level hourly vehicle type off-network activity estimates (SHP, starts, SHI, and APU hours). The emissions factors are multiplied by the appropriate off-network activity, as determined by the pollutant process-activity association (shown previously in Table 8).

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

TTI EMISSIONS ESTIMATION UTILITIES FOR MOVES2014A-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 (MOVES2014a). 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 Highway Performance Monitoring System (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, VehPopulationBuild, OffNetActCalc, MOVESactivityInputBuild, MOVESfleetInputBuild, RatesCalc, RatesAdj, and EmsCalc. The TRANSVMT and VirtualLinkVMT prepare the link VMT and speeds activity input. The VehPopulationBuild utility builds the vehicle population used to calculate the off-network activity. The OffNetActCalc utility builds the SHP, starts, SHI, and APU hours required to estimate emissions using the rate-per-activity emissions rates produced by the RatesCalc or RatesAdj utilities. The MOVESactivityInputBuild and MOVESfleetInputBuild utilities build inputs used in MOVES. The RatesCalc utility assembles the emissions rates from the MOVES output in terms of rate-per-activity, including rate-per-SHP for the evaporative emissions processes. The RatesAdj utility makes special adjustments to the emissions rates when required. The EmsCalc utility calculates emissions by hourly time periods, producing a tab-delimited summary file (including 24-hour totals), hourly link emissions output files (optional), and an optional tab-delimited summary file by MOVES source classification code (SCC).

A process flow diagram follows 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 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 EmsCalc 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 a 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, EmsCalc (as well as with other utilities to develop off-network activity estimates).

VehPopulationBuild

The VehPopulationBuild 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 EmsCalc utility to estimate emissions or the OffNetActCalc 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 <=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 14.

Table 14. 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 15 shows the SUTs and their associated registration category in the registration category data array.

Table 15. 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.

OffNetActCalc

The OffNetActCalc calculates the analysis scenario (i.e., year, season, day type) SHP, starts, SHI, and APU hours by hour, SUT, and fuel type used to estimate emissions using the EmsCalc utility. The SHI and APU hours are only calculated for SUT 62, fuel type 2 (CLhT_Diesel). The SHP is calculated using either the TDM or the 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 VehiclePopulationBuild utility). The starts activity is calculated using the SUT/fuel type population and the starts per vehicle (typically the MOVES default). The SHI and APU hours are a function of hotelling hours. This utility has two options for calculating the hotelling hours. Using the first option, the analysis scenario 24-hour hotelling hours is calculated using a user-supplied extended idle factor to the source hours operating (SHO). However, this method of estimating the hotelling hours as a direct function of the SHO does not consider the availability of locations where extended idling may occur. The second option (and suggested method) uses base data (24-hour hotelling, link VMT and speeds, and VMT mix), the analysis scenario data used to calculate the SHP, and the analysis scenario SHP to calculate the analysis scenario 24-hour hotelling hours.

For the analysis scenario first hourly VMT and speeds input, 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 each link that has the desired county code; thus distributing 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 analysis scenario VMT and speeds input; therefore producing the analysis scenario hourly values for VMT by SUT/fuel type and for VHT by SUT/fuel type.

The analysis scenario 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 is calculated by subtracting the hourly SUT/fuel type VHT (or SHO) from the hourly SUT/fuel type total hours. If the calculated SHP is negative (i.e., SHO is greater than the total hours), the SHP is set to 0.

To calculate the analysis scenario 24-hour hotelling hours under option 1 (as a direct function of SHO), the utility multiplies the CLhT_Diesel analysis scenario 24-hour SHO by the user-supplied extended idle factor, which represents the amount of extended idle time that must occur per SHO. For option 2 (as a function of base hotelling data), the utility calculates the base 24-hour CLhT_Diesel VMT using the base VMT and speeds inputs and the base VMT mix with the same procedure used in the analysis scenario SHP calculations. The 24-hour analysis scenario CLhT_Diesel VMT is then divided by the 24-hour base CLhT_Diesel VMT to create a scaling factor, which is then applied to the base 24-hour hotelling hours to calculate the analysis scenario 24-hour hotelling hours.

The utility then calculates the analysis scenario hourly hotelling hours. The analysis scenario hourly CLhT_Diesel SHO (from the SHP calculation process) is converted to hourly VHT fractions. The hourly hotelling fractions are calculated as the inverse of the hourly VHT fractions. The hourly hotelling fractions are then applied to the analysis scenario 24-hour hotelling hours to calculate the hourly hotelling hours. For each hour, the hourly hotelling hours are then compared to the hourly CLhT_Diesel SHP. For those hours where the hotelling hours are greater than the SHP, hotelling hours are set to the SHP for that hour.

The utility then calculates the SHI fraction and the APU fraction using the source type age distribution (same distribution used in the MOVES runs), the relative mileage accumulation rates, and the hotelling activity distribution. Travel fractions for SUT 62 (CLhT) by ageID (0 through 30) are calculated by multiplying the age distribution by the appropriate relative mileage accumulation rate, which is then converted into a distribution by dividing the individual travel fraction (ageID 0 through 30) by the sum of the travel fractions. These travel fractions are then applied to the appropriate operating mode fractions from the hotelling activity distribution (operating mode 200) and summed to calculate the SHI fraction. Using a similar process, the APU fraction is calculated using the operating mode fractions for operating mode 201. For each hour the analysis scenario hotelling hours are multiplied by the SHI fraction to calculate the analysis scenario SHI activity and by the APU fraction to calculate the analysis scenario APU hours.

MOVESactivityInputBuild

The MOVESactivityInputBuild utility builds the roadtypedistribution, hourvmtfraction, avgspeeddistribution, roadtype, hpmsvtypeday, sourcetyperedayvmt, 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 utility also has the option of building the sourcetypeage (adjusted to reflect the 24-hour VMT mix), starts, and hotellinghours data files in a format consistent with the MVOES input database tables using the output from the OffNetActCalc utility, along with inputs from the MOVES runs 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 EmsCalc utility);
- 24-hour or time period VMT mix by roadway type, MOVES source type, and MOVES fuel type (same as used with the EmsCalc 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;
- MOVES default database;
- Month ID, which specifies the month for calculating the output;
- sourcetypeyear, SUT age, and sourcetypeage inputs from the MOVES runs (optional, only if sourcetypeage table output is to be created);

- Starts output from the OffNetActCalc utility (optional, only if starts table output is to be created); and
- Hotelling, extended idle, and APU hours output from the OffNetActCalc utility (optional, only if hotelling table output is to be created).

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 array by MOVES roadway type (roadTypeID codes 2 through 5) is also created using the data in the VMT summary array and VMT roadway type designations. For the link road types designated a MOVES road type of 6 or 8, the VMT is added to MOVES road type 2 in the MOVES roadway type array. For the link road types designated a MOVES road type of 7 or 9, the VMT is added to MOVES road type 4 in the MOVES roadway type array. 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 MOVES roadway type array is used to produce the roadway type distribution array by MOVES SUT and MOVES roadway type. This VMT is 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. The utility writes the tab-delimited roadtypedistribution table output (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. The utility writes the tab-delimited hourvmtfraction table output (optional). 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.

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. The utility writes the tab-delimited avgspeeddistribution table output (optional). For those SUTs where the VMT mix is greater than 0, the average speed distribution array is used. Otherwise, the MOVES avgspeeddistribution default values are used.

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. The utility writes the tab-delimited roadtype table output (optional). If the ramp fraction for roadTypeID 2 is greater than 0, then roadTypeID 6 (with rampFraction equal to 0) and roadTypeID 8 (with rampFraction equal to 1) are also added to the roadtype database table. If the ramp fraction for roadTypeID 4 is greater than 0, then roadTypeID 7 (with rampFraction equal to 0) and roadTypeID 9 (with rampFraction equal to 1) are also added to the roadtype database table.

The VMT in the hourly VMT array is aggregated to create the 24-hour HPMS vehicle type VMT array. Each SUT is assigned an HPMS vehicle type (SUT 11 is HPMS vehicle type 10; SUTs 21, 31 and 32 are HPMS vehicle type 25; 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). The utility writes the tab-delimited hpmsvtypeday table output (optional).

The VMT in the hourly VMT array is also aggregated by SUT to create the 24-hour SUT VMT array. Using this VMT data, the utility writes the tab-delimited sourcetyperdayvmt output table (optional) in a format consistent with the MOVES input.

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

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 creates five other tab-delimited outputs (state, zone, zoneroadtype, monthvmtfraction, and dayvmtfraction tables) using the user-supplied inputs. For the state table (optional), the utility extracts the data from the MOVES default state database table where the state ID is 48 and writes this data to the tab-delimited state table output. For the zone table (optional), the utility extracts the data from the MOVES default zone data for the county ID greater than 48000 and county ID less than 49000 and writes this data to the tab-delimited zone table output with the start allocation factors, idle allocation factors, and SHP allocation factors replaced with values of 1.

For the zoneroadtype table (optional), the utility extracts the MOVES default zoneroadtype data where the zone ID greater than 480000 and zone ID less than 490000 and writes this data to the tab-delimited zoneroadtype table output, with the SHO allocation factors replaced with values of 1. For the monthvmtfraction table (optional), the utility extracts the data from the MOVES default monthvmtfraction table and writes the data to the tab-delimited monthvmtfraction table output with the month VMT fraction set to 1 for the user-supplied month ID and 0 for all other months. For the dayvmtfraction table (optional), the utility extracts the data from the MOVES default dayvmtfraction table and writes this data to the tab-delimited

dayvmtfraction table output with the day VMT fraction is set to 1 for the user-supplied day ID and 0 for all other months.

For the sourcetypeage table output (optional, also needed if the hoteling hours table output is to be created), the utility calculates the adjusted relative mileage accumulation rates (MAR) by multiplying the input relative MAR (categorized by SUT and age from the sourcetypeage input) by the SUT-specific relative MAR adjustment factors (one factor per SUT applied across all age categories). These adjustment factors are calculated using inventory SUT VMT fractions within each HPMS vehicle type and the sum of the SUT-specific normalized travel fractions within each HPMS vehicle type. The inventory SUT VMT fractions within each HPMS vehicle type are calculated by dividing the 24-hour SUT VMT by the 24-hour HPMS vehicle type VMT for the respective SUT.

For the sum of the SUT-specific normalized travel fractions within each HPMS vehicle type, the utility uses the same calculation procedures used by MOVES to calculate the normalized travel fractions. The SUT vehicle population is distributed to each age category using the SUT age distribution input. Using the sum of the vehicle population by HPMS vehicle type, the SUT population fraction for each age category within each HPMS vehicle type is calculated by dividing the SUT vehicle population by age by the sum of the vehicle population by HPMS vehicle type. The utility then calculates the initial travel fractions (by SUT and age) by multiplying the SUT population fraction for each age category within each HPMS vehicle type by the relative MAR input.

These initial travel fractions are then normalized within each HPMS vehicle type to produce the SUT and age-specific normalized travel fractions within each HPMS vehicle type. The utility then calculates the SUT-specific relative MAR adjustment factors by dividing the inventory SUT VMT fractions within each HPMS vehicle type by the sum of the SUT and age-specific normalized travel fractions (i.e., aggregated across the age category for each SUT); resulting in one SUT-specific relative MAR adjustment factor for each SUT.

For the starts table output (optional), the utility aggregates the SUT/fuel type hourly starts input (output from the OffNetActCalc utility) by SUT and multiplies the SUT hourly starts by the SUT age distribution (by SUT) to distribute the hourly SUT starts to each age category. The SUT hourly starts by age are written to the starts table output file, along with the user-supplied monthID, yearID, dayID (used to form the output hourDayID), and zoneID (set using the user-supplied county FIPS code).

For the hoteling hours table output (optional), the utility uses travel fractions specific to SUT 62 to distribute the hourly hoteling hours input (output from the OffNetActCalc utility) to each age category. These travel fractions are calculated by multiplying the SUT 62 age distribution by the calculated relative mileage accumulation rates (MOVES defaults adjusted so to reflect the emissions inventory 24-hour VMT mix) for each age category and dividing by the sum of the product for all the age categories. These travel fractions are multiplied by the hourly hoteling hours input and written to the hoteling hours table output, along with the user-supplied dayID (used to form the output hourDayID), monthID, yearID, and zoneID (set using the user-supplied county FIPS code).

MOVESfleetInputBuild

The MOVESfleetInputBuild utility builds the sourcetypeagedistribution database table and fuel/engine fraction inputs to MOVES using the TxDOT registration data sets and the MOVES default database tables. The TxDOT 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:

- Age registration data file, which lists 31 years of registration data for the Passenger Vehicles, 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;
- SUT data sources input, which specifies the data source for each SUT to use when building the sourcetypeagedistribution database table;
- Fuel/engine fractions data sources input, which specifies the data source for each SUT to use when building the fuel/engine fractions;
- Default sourcetypeage distribution input;
- MOVES default database; and
- Year ID file (optional, only if year is not the registration data year as in a future year analysis), which specifies the year for calculating the output.

The SUT data sources input lists the data source for each SUT, either a single county, multiple counties, state, or MOVES default. As this input is processed, the utility maintains a list of the input sources. The same applies to the fuel/engine fractions, except data source inputs are only valid for source types 52, 53, and 61 (other are not valid due to data limitations and source type 62 are all considered diesel).

For each county (or state total) in the list of the input sources, the age registration data (for the Passenger Vehicle, Motorcycles, Trucks <=6000, Trucks >6000 <=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 create the registration category data array (a total of seven categories for 31 years of data and the total) using the combinations in Table 14 (Registration Categories). The county is compared to the data sources for each SUT in the SUT data sources input. If the county is found for a given source type, then the 31 years of registration data from the source type's corresponding category in the registration category data array are added to the SUT age distribution array. Table 16 shows the source types and their corresponding registration categories.

Table 16. SUTs/Registration Categories Correlation for SUT Age Distribution.

SUT	Registration Category
11	2
21	1
31, 32	3
52, 53	4
61, 62	5

A similar process is followed for the fuel/engine fractions array. However, only SUTs 52, 53, 61, and 62 are processed due to data limitations. The registration data are saved in the fuel/engine fractions array based on fuel type. Table 17 shows the SUTs and their corresponding registration categories.

Table 17. SUTs/Registration Categories Correlation for Fuel/Engine Fractions.

SUT	Fuel Type	Registration Category
52, 53	Diesel	4
	Gas	6
61	Diesel	5
	Gas	7
62	Diesel	5 + 7
	Gas	None – all are assumed diesel

After processing all of the counties, the data from the default sourcetypeage distribution input are processed and the data for the registration data year are saved in the default age distribution array. For each source type in which the registration data are to be used for the age distribution, the 31 years of registration data in the SUT age distribution array are converted to a distribution by dividing the source type yearly registration data by the source type total registration data. For each source type in which the defaults are to be used, the defaults values from the default age distribution array are copied to the SUT age distribution array.

The MOVES default fuel/engine fractions are extracted from the MOVES default database (using the appropriate code for MySQL) and saved in the default fuel/engine fractions array. For

source types 52, 53, and 61, the source type yearly registration data in the fuel/engine fractions array are converted to fuel/engine fractions by dividing the yearly source type diesel registration data by the sum of the yearly source type diesel registration data and the yearly source type gas registration data.

If the year ID input is used, then these fuel/engine fractions are adjusted to match the year from the year ID input. If the year from the year ID input is greater than the registration data year, then the first fuel/engine fraction is extended to match the year from the year ID input and the appropriate number of years is dropped from the end of the fuel/engine fractions to maintain the appropriate distribution. If the year from the year ID input is less than the registration data year, then the last fuel/engine fraction is extended to match the year from the year ID input and the appropriate number of years is dropped from the beginning of the fuel/engine fractions to maintain the appropriate distribution. For source type 62, all of the fuel/engine fractions in the fuel/engine fractions array are set to a value of 1.

Using the appropriate MySQL code, a new `sourcetypeagedistribution` database table is created and the data from the SUT age distribution array, along with the year ID (either from the registration data or the year ID input), are used to fill the new database table. A text format of this database table may be written as well. Using the appropriate MySQL code, a new `AVFTfuelengfraction` database table is created and the data from the fuel/engine fractions array are used to fill the new database table for SUTs 52, 53, 61, and 62. For all other SUTs, the default fuel/engine fraction array data for the appropriate year (either the registration data year or the year ID input) are used to fill the new database table. A text format of this database table may be written as well.

RatesCalc

The RatesCalc utility calculates emissions rates in terms of rate/SHP for the evaporative emissions processes using the data in the CDB used in the MOVES emissions rates run and the MOVES default database. The utility also creates copies of the `rateperdistance`, `rateperhour`, and `rateperstartemissions` rate tables to include the units for each pollutant. If not specified, emissions rates are assembled for each pollutant and process combination (excluding total energy and the refueling emissions processes) in the MOVES emissions rate tables. The utility also uses the `movesrun` database table, along with a pollutant energy or mass lookup table (mass, TEQ, or gmole), to determine the units of the emissions rates, which are added to the emissions rate tables, which will allow 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 18 shows.

Table 18. MOVES2014a Emissions Process and Corresponding Activity for Rate-per-Activity Emissions Rates.

MOVES2014a Emissions Process	Activity	Emissions Rate Units
Running Exhaust	Miles Traveled	Rate/Mile
Crankcase Running Exhaust	Miles Traveled	Rate/Mile
Start Exhaust	Starts	Rate/Start
Crankcase Start Exhaust	Starts	Rate/Start
Extended Idle Exhaust	Extended Idle Hours	Rate/Extended Idle Hour
Crankcase Extended Idle Exhaust	Extended Idle Hours	Rate/Extended Idle Hour
Auxiliary Power Exhaust	APU Hours	Rate/APU Hour
Evaporative Permeation	Miles Traveled Source Hours Parked	Rate/Mile Rate/SHP
Evaporative Fuel Vapor Venting	Miles Traveled Source Hours Parked	Rate/Mile Rate/SHP
Evaporative Fuel Leaks	Miles Traveled Source Hours Parked	Rate/Mile Rate/SHP
Brake Wear	Miles Traveled	Rate/Mile
Tire Wear	Miles Traveled	Rate/Mile

For the rateperdistance (rate/mile emissions rates) emissions rate table, the utility creates a copy of the emissions rates in the specified output database with the table name `ttirateperdistance`. If specific pollutants are specified, only the emissions rates for those pollutants are copied to the `ttirateperdistance` table. Otherwise, the entire `rateperdistance` table is copied to the `ttirateperdistance` table. The utility also adds a “Units_Per_Activity” field to the `ttirateperdistance` table and fills that field based on the pollutants energy or mass designation (mass, TEQ, or gmole). For those pollutants designated as mass, the mass units from the `movesrun` table are added to the “Units_Per_Activity” field. For those pollutants designated as gmole, the mass units from the `movesrun` table, along with the text “-mole” (i.e., pound-mole or gram-mole) are added to the “Units_Per_Activity” field. For those pollutants designated as TEQ, the text “TEQ” is added to the “Units_Per_Activity” field. No unit conversions are performed in this utility. The `rateperstart` and `rateperhour`, emissions rate tables are processed in a similar manner to produce the `ttirateperstart` and `ttirateperhour`, emissions rate tables.

For the evaporative emissions rates, the utility uses the CDB from the MOVES run and the MOVES default database to replicate the MOVES vehicle population and SHP calculation process. Using the emissions rates from the `rateperprofile` and `ratepervehicle` emissions rate tables, the utility calculates the rate-per-SHP emissions rates by multiplying the emissions rate by the appropriate vehicle population and dividing by the appropriate SHP value. These rate-per-SHP emissions rates are then saved in the `ttiratepershp` emissions rate table. Similar to the

previous RatesCalc emissions rate tables, the “Units_Per_Activity” field is added to the ttiratepershp table and filled based on the pollutants energy or mass designation.

RatesAdj

The RatesAdj utility applies emissions rate adjustments to an emissions rate database table produced by RatesCalc utility (ttirateperdistance, ttirateperstart, ttirateperhour, or ttiratepershp) 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, along with the output units of the emissions rates. This allows the user to perform any unit conversions between mass units (i.e., pounds to grams or pound-mole to gram-mole) without providing any additional adjustment factors. Unit conversions between unit types (i.e., gram-moles to grams or TEQ to grams) are not performed internally by the utility. These types of conversions must be made using the emissions rate adjustment factors. 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 any unit conversion adjustments, 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. Using MySQL code, the utility also creates a minimum and maximum emissions rate summary for each input emissions rate table and the output emissions rate table by pollutant, process, and source type/fuel type, which is written to a tab-delimited file specified by the user.

EmsCalc

The EmsCalc utility estimates the hourly link emissions for one user-specified county using the emissions factors (either from RatesCalc or RatesAdj), 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 (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 EmsCalc are:

- Emissions factors from RatesCalc or RatesAdj;
- Link-based hourly VMT and speeds developed with the TRANSVMT or VirtualLinkVMT utility. For each link, the following information is input to EmsCalc:

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 (SHP, starts, SHI, and APU hours) by hour and SUT/fuel type;
- 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;
- Pollutants input file, which specifies which pollutant/process combinations for which the emissions calculations will be performed and their respective units in the tab-delimited output;
- SCC input file (optional, only if the activity and emissions by SCC are to be created); and
- SCC pollutants input file (optional, only if the activity and emissions by SCC are to be created).

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 (tirateperdistance 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. For each pollutant/process combination in the pollutants input file, 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. If the activity and emissions by SCC are to be created, the activity and emissions are also aggregated by SCC using the SCC input file and by SCC pollutant using the SCC pollutants input file (thus allowing the user the option to combine multiple MOVES pollutants into one more aggregate pollutant).

For the off-network emissions, the *tirateperstart*, *tirateperhour*, and *tiratepershp* emissions rates (by SUT/fuel type) are multiplied by the appropriate activity, which is determined by the emissions process (see Table 18). If the activity and emissions by SCC are to be created, the activity and emissions are also aggregated by SCC using the SCC input file and by SCC pollutant using the SCC pollutants input file (thus allowing the user the option to combine multiple MOVES pollutants into one more aggregate pollutant).

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. Only those pollutant/process combinations in the pollutants input file with tab-delimited output units other than “NONE” will appear in the tab-delimited output file. Prior to output, any unit conversions between mass units (i.e., pounds to grams or pound-mole to gram-mole) are performed by the utility. Unit conversions between unit types (i.e., gram-moles to grams or TEQ to grams) are not performed internally by the utility (these type of unit conversions must be done using the RatesAdj utility). 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. If specified, the tab-delimited activity and emissions by SCC output file is also created, which lists the activity and emissions for each SCC pollutant by SCC.

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:

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

Where:

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

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

$$FAC_{\text{Interp}} = \left(\frac{1}{\text{Speed}_{\text{link}}} - \frac{1}{\text{Speed}_{\text{low}}} \right) \bigg/ \left(\frac{1}{\text{Speed}_{\text{high}}} - \frac{1}{\text{Speed}_{\text{low}}} \right)$$

Given that:

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

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

$\text{Speed}_{\text{link}} = 41.2 \text{ mph};$

$\text{Speed}_{\text{low}} = 40 \text{ mph};$ and

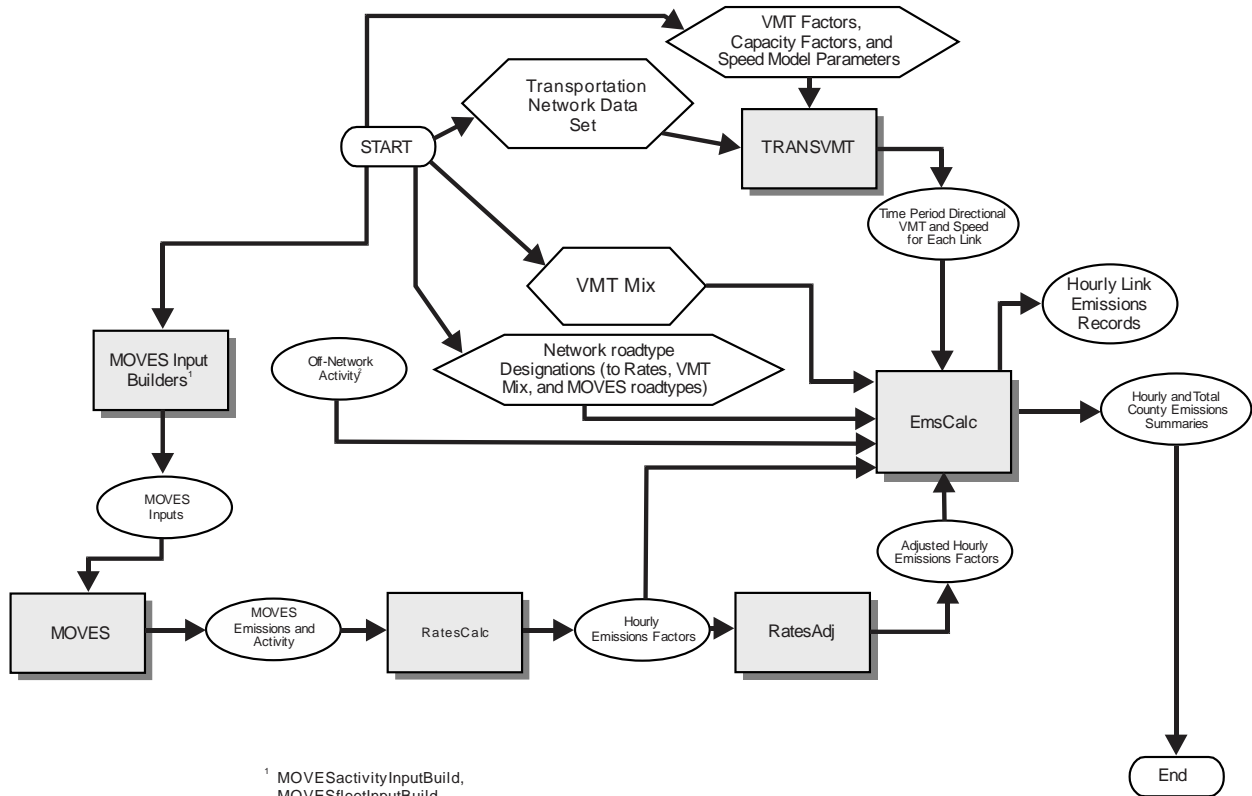
$\text{Speed}_{\text{high}} = 45 \text{ mph}.$

$$FAC_{\text{Interp}} = \left(\frac{1}{41.2\text{mph}} - \frac{1}{40\text{mph}} \right) \bigg/ \left(\frac{1}{45\text{mph}} - \frac{1}{40\text{mph}} \right) = \frac{-0.00073}{-0.00278} = 0.26214;$$

$EF_{\text{Interp}} = 0.7413 \text{ g/mi} - (0.26214) H (0.7413 \text{ g/mi} - 0.7274 \text{ g/mi});$

$= 0.7377 \text{ g/mi}.$

Travel Demand Model Network Link-Based Hourly MOVES Emissions Estimates



¹ MOVESactivityInputBuild, MOVESfleetInputBuild, MOVESmetInputBuild, and VehPopulationBuild.

² VehPopulationBuild, and OffNetActCalc.