CHAPTER 3

METHODOLOGY

This chapter reviews the methodology for developing the on-road mobile sources emission inventory for the State of Tennessee. Emissions from highway mobile sources were predicted with the latest available mobile source model, MOBILE6 that was released in January 2002. MOBILE6 is an update to the MOBILE5b model that incorporates the effects of the most recent regulations that were promulgated after the release of MOBILE5b, including LEV, Tier2/Sulfur, HDDVNOx and HDDV/Sulfur regulations. MOBILE6 not only includes new regulations but also various updates such as the ability to predict facility-based emission factor emissions for more sophisticated application of results, "real-time" diurnal emission factors, separation of "start" and "running" emissions and other relevant factors (3). This chapter also summarizes the input parameters used in the modeling and calculations of the on-road mobile sources emission projection for years 1999 through 2030.

Most of the required input parameters were set to "default" values built in to the MOBILE6 model. Locality specific input parameters were used in the MOBILE model such as VMT fractions, registration distributions, daily minimum and maximum temperatures, absolute humidity, fuel reid vapor pressure (RVP) and the option of a Inspection and Maintenance (I/M) program. In the following sections, detailed explanations of these input parameters are presented.

3.1. DEVELOPMENT OF REGISTRATION DISTRIBUTION BY AGE FOR TENNESSEE

3.1.1. Introduction

Registration distribution by age is a required input to the MOBILE6 model. It is the fraction of vehicles on the road by vehicle class and age. Although the model allows the use of a national default distribution, inventory guidance requires the use of locality specific distributions where these are available. The MOBILE6 model uses the registration distribution along with annual mileage accumulation rates to evaluate the travel fractions, which in turn are used to weight the emission factors according to the age distribution of the fleet. Hence area specific values may make a difference in the mobile source emission values. For the purpose of this study it is more appropriate to use values developed specifically for the State of Tennessee. Specific registration distribution by age may be developed from different sources such as the registration data, inspection and maintenance data and so on. For this study, area specific registration distributions were developed from the registration data obtained from the Tennessee Department of Safety, Title and Registration Division.

3.1.2. Methodology

Registration data provided by the Tennessee Department of Safety, Title and Registration Division were received on a 3480 cartridge and were in the form of a text file format which was then imported into Microsoft Access®, a database software, to be analyzed further. The data contained information on the county, registration class, make code, model year and body type for vehicles of model year 2001 and earlier. For the purpose of this study, only the following information was used: county, model year, registration class code and the body type. Each county is represented by a two-digit number. Model year is another field in the database that shows the last two digits of the year the vehicle was manufactured. The registration class code gives information on the class under which the vehicle is registered such as a privately owned car, a state owned car or truck, trailers, mobile homes, etc. It also has information on the gross vehicle weight (GVW) for certain classes, which was primarily useful in identifying heavy duty trucks. Lastly the body type code field differentiates the types of vehicles within the main categories of passenger cars, trucks and motorcycles.

For purpose of calculations, the count data for each county were grouped into six area subgroupings (most of which corresponded to a Metropolitan Statistical Area (MSA)):

1. Shelby/Tipton/Fayette Counties (denoted as "*Shelby +*")
2. Davidson/Sumner/Wilson/Williamson/Rutherford Counties (denoted as "*Davidson +*")
3. Hamilton/Marion Counties (denoted as "*Hamilton +*")
4. Knox/Anderson/Loudon/Blount/Sevier/ Union MSA + Jefferson County (denoted as "*Knox +*")
5. Sullivan/Hawkins/Washington/Carter/Unicoi Counties (denoted as "*Sullivan +*")
6. All Other TN Counties (denoted as "*All Other Counties*")

Prior to start of data analysis, any inherent errors in the database such as blank fields (fields without any value/entry) and county number greater than 95 were identified and removed from the database. County number greater than 95 were removed because Tennessee has only 95 counties. The county code information was used to identify and group the data into the different Area Subgroupings. Registration distributions were developed only for two major vehicle categories: light-duty vehicle (LDV, passenger cars less than 8500 lbs GVW), and light-duty trucks (LDT1 and LDT2, less than 6000 lbs GVW; LDT3 and LDT4, 6001-8500 lbs GVW). Body type codes were used to identify the vehicle classification (LDV or LDT). The registration class code was useful in identifying heavy duty trucks. Hence a combination of the body type code and the registration class code was used to classify vehicles as LDV and LDT and to avoid all other vehicle categories from being counted. Since no detailed information was available to evaluate the fractions separately within the light duty truck category (LDT1, LDT2, LDT3 or LDT4), these were grouped together into a single truck category (LDT). Table 3-1 lists the body type codes and registration class codes used to identify and group the two vehicle classifications.

After the vehicles were grouped into the two vehicle categories within each Area Subgroup, the registration fraction was calculated as follows: actual counts of vehicle were collected for each age vehicle starting with two year old vehicles to thirty year old vehicles. The age, for purpose of evaluation, was defined as the number of years that the vehicle had been in service; for example, model year 2000 (for the database of year 2001) was defined as a two year old vehicle. The thirty year old vehicle included all vehicles that were thirty years old and greater. The number of one year old vehicles was assumed to be 75% of the two year old vehicle counts. This is to account for the fact that the

Table 3-1. Body Type and Registration Class Code for Different Vehicle Classifications

LDV		LDT	
Body Type code	**Description**	**Body Type code**	**Description**
4D, 4T, 4H, 4L, 4P	4-Door sedans	PK	Pickup Trucks
2D, 2H, 2L, 2P, 2T	2-Door sedans	VC, VD, VN, VT, VW	Vans
3D, 3P, CP	Coupe	UT	Utility (Blazer and Jimmy)
SW	Station Wagons (as LDVs)	MV	Maxi-Van
CV	Convertible	SV	Sport Vans
SD, SB, SC, 5D, HR, HS, HT, HP, LB	Other Sedans, Coupes and Hatchbacks	JP, LL	Jeep and Carryall
LM, LS	Limousines	3C, 4B, 4C	Extended Cab Trucks
		CB, CC, CG, CH, CL, CM	Custom Pickup
		MH	Camper / Motorhome
		B1, BU	Light Buses
		IC, IE, MY	Incomplete Chassis / Motorized Cutaway
		PN, TB, TL, TM, TN, TR	Miscellaneous Trucks
		CW, CY, DP	Light Cargo and Dump Trucks
		AM	Ambulance

Allowed Registration Class Codes:

any of the following - Greater than or equal to 1000 and less than 4000
6000 to 7000, both inclusive

new cars were assumed to enter into service in the month of October and they have been through only 75% of a year by July 1 (the evaluation month). Using the vehicle counts, the fraction of vehicles in each age category was calculated and plotted. These fractions represent the registration distribution by age. However, the plots do not follow a smooth curve and reflect socio-economical changes that might have occurred over the last thirty years. Since this same data will also be used for estimation of the registration for future years, a best-fit curve was fit to each registration distribution to smooth out the year to year fluctuations. Since the plots depicted curves similar to a bell-shaped or gaussian curve, a gaussian distribution equation was chosen to fit the data set. Sigma Plot® software was used for this purpose.

This method is based on the formula shown below:

$$y = \frac{k}{s}\exp\left(-\frac{1}{2}\left(\frac{x-m}{s}\right)^2\right) \qquad (3.1)$$

where:

y = fraction of vehicles at age x, unitless

k = constant (empirically derived age), years

s = standard deviation of the distribution, years

m = mean of the distribution; represents the age with the highest fraction (where the curve peaks), years

x = age of the vehicle, years

The curve fit function in Sigma Plot® was used to generate best fit values for k, s and m. Since the registration fractions are required to sum up to 1.0, the 'k' value was adjusted until this was achieved. This final 'k' value and the earlier generated 's' and 'm' values, along with coefficient of determination for best fit (R^2), for the various Area Subgroups and vehicle classifications are listed in Table 3-2.

The registration distribution developed for each Area Subgroup for the three major vehicle classifications is tabulated in Tables 3-3, 3-4. The graphs showing the raw fractions and best-fit curves are shown in Appendix A in Figures A1 through A6.

Table 3-2. Gaussian Equation Parameters

LDV:

County	k	m	s	R^2
Shelby +	0.6844	2.5797	8.7591	0.9941
Davidson +	0.6263	3.4574	8.0146	0.9931
Hamilton +	0.5019	7.0683	7.8563	0.9849
Knox +	0.5727	5.3314	8.9611	0.9866
Sullivan +	0.4696	8.6746	7.7825	0.9774
All Other Counties	0.4628	8.5120	7.1341	0.9872

LDT (LDT1, 2, 3 and 4):

County	k	m	s	R^2
Shelby +	0.7979	0.7700	9.9579	0.9806
Davidson +	0.6890	2.4667	8.6599	0.9849
Hamilton +	0.7282	2.2967	11.1308	0.9692
Knox +	0.9410	-1.6265	13.3863	0.9729
Sullivan +	0.6099	5.5319	11.2862	0.9507
All Other Counties	0.5479	7.0948	10.0499	0.9562

Table 3-3. Age Distributions for LDV

Age	Shelby +	Davidson +	Hamilton +	Knox +	Sullivan +	All Other Counties
1	0.0592	0.0641	0.0446	0.0481	0.0355	0.0298
2	0.0780	0.0769	0.0519	0.0596	0.0418	0.0428
3	0.0780	0.0780	0.0559	0.0618	0.0463	0.0481
4	0.0771	0.0780	0.0592	0.0632	0.0504	0.0531
5	0.0752	0.0767	0.0617	0.0639	0.0540	0.0575
6	0.0724	0.0743	0.0633	0.0637	0.0569	0.0610
7	0.0688	0.0709	0.0639	0.0628	0.0590	0.0634
8	0.0645	0.0665	0.0634	0.0611	0.0601	0.0647
9	0.0597	0.0615	0.0620	0.0588	0.0603	0.0647
10	0.0546	0.0560	0.0596	0.0558	0.0595	0.0635
11	0.0492	0.0502	0.0564	0.0523	0.0577	0.0610
12	0.0438	0.0443	0.0525	0.0485	0.0551	0.0576
13	0.0385	0.0385	0.0480	0.0443	0.0517	0.0532
14	0.0334	0.0329	0.0433	0.0400	0.0477	0.0483
15	0.0286	0.0277	0.0384	0.0357	0.0434	0.0429
16	0.0242	0.0230	0.0335	0.0315	0.0387	0.0374
17	0.0202	0.0187	0.0287	0.0274	0.0340	0.0320
18	0.0166	0.0151	0.0243	0.0235	0.0294	0.0268
19	0.0135	0.0119	0.0202	0.0200	0.0250	0.0220
20	0.0108	0.0093	0.0165	0.0167	0.0209	0.0177
21	0.0086	0.0071	0.0133	0.0139	0.0172	0.0140
22	0.0067	0.0054	0.0105	0.0113	0.0139	0.0109
23	0.0052	0.0040	0.0082	0.0091	0.0111	0.0082
24	0.0039	0.0029	0.0063	0.0073	0.0087	0.0061
25	0.0030	0.0021	0.0047	0.0057	0.0067	0.0045
26	0.0022	0.0015	0.0035	0.0045	0.0051	0.0032
27	0.0016	0.0010	0.0026	0.0034	0.0038	0.0023
28	0.0012	0.0007	0.0018	0.0026	0.0028	0.0016
29	0.0008	0.0005	0.0013	0.0020	0.0020	0.0010
30	0.0006	0.0003	0.0009	0.0014	0.0014	0.0007
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 3-4. Age Distributions for LDT (LDT1, 2, 3 and 4)

Age	Shelby +	Davidson +	Hamilton +	Knox +	Sullivan +	All Other Counties
1	0.0613	0.0607	0.0456	0.0577	0.0427	0.0369
2	0.0795	0.0794	0.0654	0.0678	0.0515	0.0479
3	0.0781	0.0794	0.0653	0.0662	0.0527	0.0502
4	0.0760	0.0783	0.0647	0.0644	0.0535	0.0520
5	0.0732	0.0762	0.0635	0.0622	0.0540	0.0533
6	0.0698	0.0732	0.0619	0.0598	0.0540	0.0542
7	0.0659	0.0694	0.0598	0.0571	0.0536	0.0545
8	0.0616	0.0649	0.0574	0.0543	0.0528	0.0543
9	0.0569	0.0599	0.0546	0.0513	0.0515	0.0535
10	0.0521	0.0545	0.0515	0.0482	0.0500	0.0523
11	0.0473	0.0490	0.0482	0.0451	0.0481	0.0505
12	0.0424	0.0434	0.0447	0.0419	0.0459	0.0484
13	0.0377	0.0380	0.0412	0.0387	0.0434	0.0459
14	0.0331	0.0328	0.0376	0.0356	0.0408	0.0431
15	0.0289	0.0279	0.0341	0.0325	0.0380	0.0400
16	0.0249	0.0235	0.0307	0.0295	0.0351	0.0368
17	0.0212	0.0195	0.0273	0.0267	0.0322	0.0335
18	0.0179	0.0159	0.0242	0.0240	0.0294	0.0303
19	0.0150	0.0129	0.0212	0.0214	0.0265	0.0270
20	0.0124	0.0102	0.0185	0.0191	0.0238	0.0239
21	0.0102	0.0081	0.0159	0.0168	0.0211	0.0209
22	0.0083	0.0063	0.0137	0.0148	0.0186	0.0181
23	0.0066	0.0048	0.0116	0.0129	0.0163	0.0156
24	0.0053	0.0036	0.0098	0.0112	0.0142	0.0132
25	0.0042	0.0027	0.0082	0.0097	0.0122	0.0111
26	0.0032	0.0020	0.0068	0.0084	0.0104	0.0093
27	0.0025	0.0014	0.0056	0.0071	0.0089	0.0077
28	0.0019	0.0010	0.0045	0.0061	0.0074	0.0063
29	0.0014	0.0007	0.0037	0.0051	0.0062	0.0051
30	0.0011	0.0005	0.0030	0.0043	0.0052	0.0041
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

3.1.3. Use of Developed Registration Fractions in MOBILE6 Model

The developed registration fractions were used for mobile source emission calculations using the MOBILE6 model for areas within Tennessee. For those Area Subgroups listed above, the corresponding calculated fractions were used for the LDV, and the LDT (LDT1, 2, 3 and 4) vehicle categories; national default values were used for the remaining 11 vehicle categories. For the case of "All Other Counties" the following approach was used: when the total interstate (freeway + interstate) DVMT exceeded 50% of the total DVMT for a particular county, national default values were used instead of the generated fractions. This is based on the assumption that, in a rural county that has a major interstate flowing through it, the majority of vehicles on the interstate may not necessarily be those that are registered in that county and are most likely a part of the "through" traffic. Hence, the registration data for that county would not provide information that would be representative of the actual vehicle mix that is on the road. For counties that had interstate DVMT that is less than 50% of the total DVMT for the county, the "All Other Counties" calculated fractions were used for the LDV and LDT categories; National default values were used for the rest.

3.2. DEVELOPMENT OF VMT MIX FRACTIONS FROM THE TENNESSEE VEHICLE REGISTRATION DATA

3.2.1. Introduction

The VMT mix represents the fraction of vehicle miles traveled (VMT) that is accumulated by each vehicle category on the highway. For example, if the VMT mix fraction for Light Duty Vehicles (LDV) is 60%, then it implies that 60% of the total

VMT is accumulated by LDV on the highway. It was realized in this study that the VMT mix data provided by TDOT was not suitable for mobile source emission modeling due to the discrepancy in the way LDV and LDT were defined in the data collection process by TDOT versus the way that the U.S.EPA defines these categories (i.e. all minivans, SUVs etc., are LDT based on U.S.EPA emission standards). TDOT vehicle mix data were obtained from actual vehicle counts on the highway, which were performed by automated counters and were allocated to LDV or LDT category based on the axle distance of the vehicle. This approach, however, does not conform to the EPA's MOBILE6 definition of LDV and LDT. A LDT may be allocated to LDV category if the axle distance was comparable to that of a car. Thus, while the data generated by the TDOT procedure for the LDV and LDT category is suitable for some uses, it is not suitable for use in allocating emissions by vehicle type for LDV and LDT categories. However, the TDOT-generated data were assumed to be correct for the heavy duty vehicle categories. In addition, visual counts performed by researchers at UTK on the interstates and highways around the Knoxville area, revealed that the information on VMT mix for LDV and LDT categories were substantially different from that provided by TDOT. It was thus necessary to come up with an approach to develop the VMT mix fractions for the LDV and LDT categories. The following section summarizes the procedure that was followed in developing these fractions based on the State's vehicle registration data.

3.2.2. Methodology

The VMT mix information originally provided by TDOT had VMT mix fractions for the following vehicle categories (as per definition of MOBILE5b): LDGV, LDGT1, LDGT2, HDGV, LDDV, LDDT, HDDV and MC. In the following discussion, the vehicle classifications referred to are according to Mobile5b definition. Of the above eight categories, new VMT mix fractions were developed only for LDGV, LDGT1 and LDGT2 categories. The fractions for the remaining categories were unchanged and were assumed to remain constant over time (2000 to 2030). VMT mix fractions for the different vehicle categories were developed from the vehicle registration data. Analysis of the registration data gives information on the fraction of LDV, LDT etc., that were registered in the State of TN. These fractions may or may not represent the VMT fraction of each of those vehicle categories on the road depending on the vehicle miles traveled by each of those categories. For example, even if the number of registered trucks is less than that for cars, their VMT fractions need not necessarily be less than that of the cars, because of the fact that they are driven more miles than cars. As explained in section 3.1, vehicle registration information was analyzed for LDV and LDT vehicle classifications only. Thus, the readily available data on the *number* of registered LDV and LDT vehicles had to be expressed on a different basis in terms of *vehicle miles driven* by LDGV, LDGT1 and LDGT2 vehicle classifications. This was accomplished by multiplying the vehicle counts (number of registered vehicles) in each category by the miles per year driven by the respective vehicle category. The resulting values, which are the total miles driven by each vehicle category, were then expressed as a fraction of the total miles driven by all vehicle categories summed together, to obtain the VMT Mix fraction. It must be noted that while the VMT Mix fractions were being developed for LDGV, LDGT1 and LDGT2 categories (two truck classifications), available counts were for Light duty vehicles (LDV) and Light duty Trucks (LDT – all truck sub-classifications combined) each of which include both gasoline and diesel. Although the vehicle counts obtained for LDV and LDT include diesel vehicles in addition to gasoline vehicles, it was assumed that the percentage of diesel vehicles small and would create a negligible change in the relative fractions of LDGV and LDGT. Hence, the LDV and LDT vehicle counts (which include diesel vehicles) were assumed to be representative of LDGV and LDGT counts. Also, it was necessary to find VMT fractions for the two light duty truck classifications, LDGT1 and LDGT2, from the vehicle counts for the whole light duty truck category (LDT). This was done using the default ratio of LDGT1 to LDGT2 available in the MOBILE6 model. In order to proceed with the calculation, the following parameters were needed: miles per year driven by LDGV, miles per year driven by LDGT and the default ratio of LDGT1 to LDGT2 in MOBILE6. The vehicle miles driven by any vehicle in each year is represented by the annual mileage accumulation rate (AMAR) values in the MOBILE6 model. In the MOBILE6 model, AMARs are available for LDGV, LDGT1 and LDGT2 by age. Since the number of vehicles in each vehicle classification is a total count of all age vehicles, an average value of AMAR (weighted by age mix) was determined for each of the vehicle classification (LDGV, LDGT1 and LDGT2) as per the equation below:

$$Average\ AMAR = \sum_i \left[\left(fraction\ of\ registered\ vehicles \right)_i \times \left(AMAR \right)_i \right]$$

where

i = age of vehicle

(fraction of registered vehicles)$_i$ = fraction of vehicles in each age based on the TN vehicle registration data

$(AMAR)_i =$ EPA default MOBILE6 annual mileage accumulation rate for each vehicle age.

Also, since there was a value for both LDGT1 and LDGT2, a single value for the combined truck category (LDT) needed to be determined. This was done by multiplying the miles/year value (AMAR value) for each vehicle classification (LDGT1 and LDGT2) by the respective EPA default MOBILE6 vehicle count fraction and summing them up to yield a single value. The procedure for calculating the EPA default vehicle count fraction was essentially tracing back through the VMT mix fraction calculation. The following equations guide through the calculation process:

$$fraction\ x_1 = \frac{Default\ VMT\ Mix\ fraction\ of\ LDGT1\ (as\ \%\ of\ light\ duty\ category)}{Default\ AMAR\ (weighted\ by\ age\ mix)\ for\ LDGT1}$$

$$fraction\ x_2 = \frac{Default\ VMT\ Mix\ fraction\ of\ LDGT2\ (as\ \%\ of\ light\ duty\ category)}{Default\ AMAR\ (weighted\ by\ age\ mix)\ for\ LDGT2}$$

where x_1 and x_2 are fractions proportional to the default MOBILE6 vehicle counts of LDGT1 and LDGT2 respectively. The ratios of x_1 to $(x_1 + x_2)$ and x_2 to $(x_1 + x_2)$ yield the EPA default MOBILE6 vehicle count fractions of LDGT1 and LDGT2, respectively. Using these fractions, a single AMAR value for LDGT was determined as explained earlier.

Using the AMAR values for LDGV available in the MOBILE6 model, and the calculated AMAR value for LDGT, the total miles driven per year by LDGV and LDGT were determined for each of Area Subgroups by multiplying the locality specific LDV and LDT vehicle counts by the EPA MOBILE6 default AMAR values. Each of these individual values, when expressed as a fraction of the total miles driven by both LDGV and LDGT, give the VMT mix fraction for the respective vehicle category as a fraction of the light duty category. LDGT was proportioned into LDGT1 and LDGT2 based on the national default mix of 74.4% and 25.6%, respectively.

Thus, VMT mix values for LDGV, LDGT1 and LDGT2 were generated for the year 2000. These were then linearly extrapolated to the 2008 default VMT Mix fractions (expressed as a percent of the light duty category) assumed by the MOBILE6 model. The VMT mix fractions for years after 2008 were assumed to be the same as the MOBILE6 default fractions. The time frame 2008 was chosen since EPA assumed that the ratio of LDV to LDT vehicle sales would stabilize nationwide at a 40:60 ratio by the year 2008. For the vehicle categories other than LDGV, LDGT1 and LDGT2, it was assumed that the VMT fractions provided by TDOT were correct and that they would remain unchanged for future years.

The above approach yields a table of VMT fractions (expressed as a percent of the light duty category) for years 2000 through 2030. These VMT fractions were then normalized over the whole fleet in a manner such that the total percentage of (LDGV + LDGT1 + LDGT2) was equal to 100 percent minus the percentage of (HDGV + LDDV + LDDT + HDDV + MC). For example, consider the following as part of the original VMT Mix values provided by TDOT:

LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	Total
0.664	0.142	0.034	0.034	0.007	0.002	0.115	0.002	1.000

In this case, the sum of the VMT fractions for the light duty category (LDGV+LDGT1+LDGT2) is 0.84. That is, 84% of the VMT of the whole fleet is accumulated by the light duty category. Since the values of LDGV, LDGT1 and LDGT2 were determined by the approach explained earlier in this document, they have to be substituted for the values in the above table. If, for example, say the VMT mix (as a percent of the light duty category) calculation for a particular case turns out to be

LDGV = 0.5223, LDGT1 = 0.2888 and LDGT2 = 0.1889

then, the normalized values would be

LDGV = 52.23% of 0.84 = 0.4387

LDGT1 = 28.88% of 0.84 = 0.2426

LDGT2 = 18.89% of 0.84 = 0.1587

Thus the new table would contain the following values as VMT fractions for the whole fleet:

LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	Total
0.4387	0.2426	0.1587	0.034	0.007	0.002	0.115	0.002	1.000

This approach was followed for the each of the Area Subgroups for which the registration distribution was developed.

Shift from MOBILE5b vehicle classification to MOBILE6 classification

The VMT Mix fraction input to the MOBILE6 model requires 16 vehicle classes. Thus, adjustments to the MOBILE5b-based VMT Mix fractions were necessary. Table 3-5 lists the approach that was used to convert from VMT Mix fractions based on the MOBILE5b definition to VMT Mix fractions based on the MOBILE6 definition. The LDV category included gasoline and diesel cars. The percentages that were used to apportion LDGT1,

Table 3-5. Conversion from MOBILE5b based VMT Mix to MOBILE6 based VMT Mix

MOBILE6 based vehicle definition	Calculation/Adjustment made to MOBILE5b based fraction
LDV	LDGV + LDDV
LDT1	0.231(LDGT1 + LDDT)
LDT2	0.769(LDGT1 + LDDT)
LDT3	0.692(LDGT2)
LDT4	0.308(LDGT2)
HDV2B	HDGV
HDV3	0
HDV4	0
HDV5	0
HDV6	0
HDV7	0
HDV8A	0.231(HDDV)
HDV8B	0.769(HDDV)
HDBS	0
HDBT	0
MC	MC

LDDT, LDGT2 into the respective MOBILE6 truck category were based on the default ratios in MOBILE6. The heavy duty categories of MOBILE5b (HDGV and HDDV) were assigned to eight classes of heavy duty vehicles as follows. It was assumed that the HDV2B category of MOBILE6, consisted of mostly gasoline vehicles. Hence all the HDGV VMT Mix of MOBILE5b was assigned to the HDV2B class of MOBILE6. Similarly, the HDV8 class of MOBILE6 consisted of primarily diesel vehicles. Hence the HDDV VMT Mix of MOBILE5b was assigned to HDV8A and HDV8B in the ratio of 0.231 and 0.769. The ratios were based on default ratios in the MOBILE6 model. The VMT Mix fraction for the other classes of the heavy duty category were set to zero. The VMT Mix for the diesel school bus and commercial diesel bus were also set to zero.

3.2.3. Use of Developed VMT Mix in MOBILE6 model

Locality specific VMT mix values were provided by TDOT for the following Counties: Knox, Davidson, Rutherford, Sumner, Williamson, Wilson, Hamilton and Shelby. As mentioned earlier, these fractions were used unchanged for vehicle classifications other than LDGV, LDGT1 and LDGT2 and calculated values were used for LDGV, LDGT1 and LDGT2. For the "All Other Counties" subgroup and the "Sullivan +" subgroup, VMT mix fractions for the vehicle classifications other than LDGV, LDGT1 and LDGT2 were assumed to be the arithmetic average of the VMT mix fractions of the available eight Counties. The VMT mix fractions for LDGV, LDGT1 and LDGT2 for these two subgroups were determined as per the procedure explained in section 3.2.2. The same VMT mix values were used for all the Counties within a subgroup. The developed VMT Mixes are shown in Appendix B.1 (Tables B.1-1 through B.1-10).

3.3. DEVELOPMENT OF THE ON-ROAD MOBILE SOURCES EMISSION INVENTORY FOR THE STATE OF TENNESSEE

3.3.1. Emissions Calculation Methodology

Emission factors generated from the MOBILE6 model were in terms of grams/mile of travel. Therefore, when the factor is multiplied by the daily vehicle miles traveled (DVMT) it gives the emissions in units of mass/day (e.g. tons per day). The baseline year calculations were done for 1999, the latest year for which Tennessee DVMT data by county for each functional roadway classifications were available at the time of this study. The baseline DVMT were then projected for future year emission calculations as explained in Chapter 2 (i.e., a linear extrapolation of the straight line fit to the 1990-1999 DVMT data by county in Tennessee). It was assumed in the calculations that the DVMT increase per year for each county would remain constant in the future and equal to the value determined for the period 1990 through 1999 for that county, per TDOT recommendation.

For each subgroup, the MOBILE6 runs were done separately for RURAL and URBAN roadway classifications. Also for counties which had an existing inspection and maintenance (I/M) program, it was also necessary to run the MOBILE6 model "with" and "without I/M" program in order to address the fact that not all vehicles which drive through a county were subject to the I/M requirement. Emission calculations for counties with I/M programs were calculated according to the following equation:

Composite Emissions in tons/day =

$$\{[(EF\ with\ I/M) * (f1)] + [(EF\ without\ I/M) * (f2)]\} * DVMT*1.102x10^{-6} / SAF \qquad (3.2)$$

where

EF = composite emission factor from MOBILE runs with/without I/M, g/mile

f1 = fraction of vehicles that have been subject to I/M that drive through the county

f2 = fraction of vehicles that have not been subject to I/M that drive through the county

SAF = seasonal adjustment factor for DVMT

$1.102x10^{-6}$ = conversion factor to convert grams to tons.

For those counties that are not subjected to the I/M program, Equation 3.3 was used for the emission calculation, as follows:

$$Composite\ Emissions\ in\ tons/day = (EF\ without\ I/M) * DVMT*1.102x10^{-6} / SAF \qquad (3.3)$$

where

EF = emission factor from MOBILE runs without I/M, g/mile

SAF = seasonal adjustment factor for DVMT

$1.102x10^{-6}$ = conversion factor to convert grams to tons.

The composite emission factor in the equation is the sum of emissions by roadway type from the MOBILE runs. These emission factors from the MOBILE runs are weighted by vehicle type and VMT mix for each roadway classification and the emission factors were reported by roadway classification for each particular analysis year.

The SAF is a factor that is used to adjust the average daily vehicle miles traveled to that of a typical average summer day. The values were obtained from TDOT and were developed from the 1996 monthly variation factors that describe the changes in the VMT by day of the week for every month. The SAF factor used in this study was taken to be the average of the monthly variation factors for each of the seven days of the week for the three months: June, July and August. This was done so that the DVMT would be representative of a typical summer (weekend and weekdays combined) day. Table 3-6 shows a tabulation of the SAF values used in Equation 3.2 and 3.3.

Table 3-6. Seasonal Adjustment Factors (SAF)

Roadway Classification	**SAF**
Rural Freeway	0.912
All Other Rural Roadway Types	0.973
All Urban Roadway Types	0.985

MOBILE6 provides for the calculation of emission factors for interstate, ramp, arterial, and local roadway classification. However, DVMT for each county in Tennessee (as provided by TDOT) does not include values for the "ramp" classification at the present time but includes interstate (interstate + freeway), principal and minor arterial, collector and local classification. To address this issue, it was assumed that the DVMT on "Urban Ramps" was 8% of the total DVMT allocated to the Urban Interstate/freeway category in the TDOT DVMT data. This was based on information provided in a recent

EPA report (12). Consequently, the DVMT that was allocated to the "Urban Interstate/Freeway" was 92% of the total DVMT on Urban Interstate/Freeways and DVMT for "Urban Ramps" was 8%. For the case of "Rural Ramp," it was assumed that the DVMT on the ramps was insignificant when compared to the DVMT on the interstates on the basis that most of the rural interstate VMT is "through" traffic not using ramps, ramp lengths are very small compared to interstate length and ramps were less frequent and further apart than in urban areas. Therefore, DVMT on "Rural Ramp" was set to zero. The DVMT on the "Arterial" classification was taken to be the sum of the DVMT on the "Principal Arterial", "Minor Arterial" and "Collector" roadway types, since MOBILE6 only contains one "arterial" roadway classification.

3.3.2. MOBILE6 Input Parameters for Area Subgroups

MOBILE6 runs were done for all the area subgroups as mentioned in the previous section. For Shelby County, Knox County and the Davidson+ area subgroup, most of the input parameters were based on the information available from the respective MPO Long Range Transportation Plans. Locality specific temperature, absolute humidity, and registration distribution data were generated. Daily minimum and maximum temperature is a required input to the MOBILE model. These temperatures were determined by selecting the average of the maximums and the average of the minimums on those days that recorded the 10 highest 8-hr average ozone concentrations for the period of 1998-2000. This was done separately for East, Middle and West Tennessee. The absolute humidity (in terms of grains per pound) was calculated according to the following equations:

$$\text{Absolute Humidity} = \left(\frac{\text{SH} \times 15.43}{2.205}\right) \tag{3.4}$$

$$\text{SH} = \left(\frac{(0.62197 \times \text{VPa})}{\text{Pm} - (0.37803 \times \text{VPa})}\right) \times 1000 \tag{3.5}$$

$$\text{VPa} = 6.11 \times 10 \times \left(\frac{(7.5 \times \text{Tdc}}{(237.7 + \text{Tdc})}\right) \tag{3.6}$$

where

SH = Daily Average Specific Humidity, g/kg

0.62197, 0.37803, 6.11, 7.5, 237.7 = constants, unitless

Pm = Atmospheric Pressure, milibars

VPa = Daily Average Actual Vapor Pressure, milibars

Tdc = Daily Average Dewpoint Temperature, Celsius

Absolute Humidity = Daily Average Absolute Humidity, grains/lb

15.43 = conversion factor to convert grams to grains

2.205 = conversion factor to convert kilograms to pounds

Absolute humidity was calculated for the following combinations: Minimum temperature and maximum relative humidity; and maximum temperature and minimum relative humidity. The minimum of these two values was found for each of the days selected. The average of those minimums was used for modeling. Although the EPA technical guidance (13) suggests the use of either the lowest of the minimum values or the value of minimum absolute humidity that would not exceed 100% saturation, it was felt that, for purposes of modeling, the average of the minimums was representative compared to either of the extremes. The results of the temperatures and absolute humidity analyses for East, Middle and West Tennessee are listed in Table 3-7a through 3-7c respectively for the period of 1998-2000. For the purpose of this study, the counties that were classified into East, Middle, and West Tennessee are illustrated in Figure 3-1 and a list of the counties included in each area is tabulated in Table C1.

3.3.3. Specific Input Parameters For MOBILE6 Runs

The input file to the MOBILE6 model consists of three sections: the Header Section, the Run Section, and the Scenario Section. The Header Section controls the overall input, output, and execution of the program. The Run Section defines parameter values that localize or customize the runs. Details and calculation of emission factors for individual scenarios are included in the Scenario Section.

3.3.3.1. Shelby + Subgroup

For the Shelby+ subgroup, two runs were done separately for Shelby County and Tipton/Fayette County. This was because Shelby County had an ongoing I/M program and assumed future anti-tampering program, while the other two counties did not. Moreover, there were slight changes in parameters such as the fuel RVP etc. Most of the input parameters for Shelby County were developed based on the information available from the Memphis MPO Long Range Transportation Plan. The input parameters are tabulated separately for Shelby County and for Tipton and Fayette Counties in Tables D2 and D3, respectively.

Table 3-7. Highest 8-hr Maximum Ozone Levels

a. East Tennessee: 1998-2000

Rank	O_3 (ppb)	Date	Name of the Monitor	Tmax (°F)	Tmin (°F)	Minimum Specific Humidity (gr/lb)
1	123	Aug-25-98	Knox21	91	65	82
2	122	Jun-01-00	Knox102	86	63	84
3	121	Jul-23-99	Blount102	93	72	116
4	118	Aug-06-98	Knox21	90	65	90
5	117	Jun-26-98	Knox21	94	72	113
6	116	Sep-12-98	Blount101	90	55	59
7	116	Jul-03-99	Jefferson	90	69	103
8	115	Aug-28-98	Knox21	94	67	83
9	115	Jul-04-99	Jefferson	91	71	108
10	115	Jun-09-00	Sullivan3	85	58	73
Average				**90**	**66**	**91**

b. Middle Tennessee: 1998-2000

Rank	O_3 (ppb)	Date	Name of the Monitor	Tmax (°F)	Tmin (°F)	Minimum Specific Humidity (gr/lb)
1	120	Aug-17-99	Wilson	97	67	71
2	114	Sep-06-99	Lawrence	92	66	70
3	111	Aug-05-98	Sumner7	89	68	92
4	111	May-18-98	Williams	87	53	53
5	110	Aug-04-98	Sumner7	87	69	86
6	110	Sep-04-99	Sumner7	96	70	79
7	110	Sep-05-99	Sumner7	99	65	56
8	108	Jun-25-98	Sumner7	96	74	111
9	108	Sep-03-99	Lawrence	96	62	56
10	108	Jun-01-00	Sumner7	88	64	79
Average				**93**	**66**	**75**

c. West Tennessee: 1998-2000

Rank	O_3 (ppb)	Date	Name of the Monitor	Tmax (°F)	Tmin (°F)	Minimum Specific Humidity (gr/lb)
1	124	May-18-98	Shelby21	91	64	62
2	110	Jul-09-99	Shelby21	92	76	126
3	109	Aug-23-98	Shelby100	93	69	87
4	108	Aug-28-98	Shelby100	97	68	94
5	107	Jul-26-00	Shelby21	95	70	70
6	107	Sep-06-98	Shelby100	97	74	91
7	107	Sep-04-99	Shelby21	96	70	105
8	106	Sep-19-99	Shelby21	92	63	48
9	104	May-21-98	Shelby100	92	72	93
10	104	May-19-98	Haywood1	92	70	79
10	104	Aug-22-00	Shelby21	100	77	106
10	104	Aug-19-99	Shelby21	97	73	90
Average				**95**	**71**	**88**

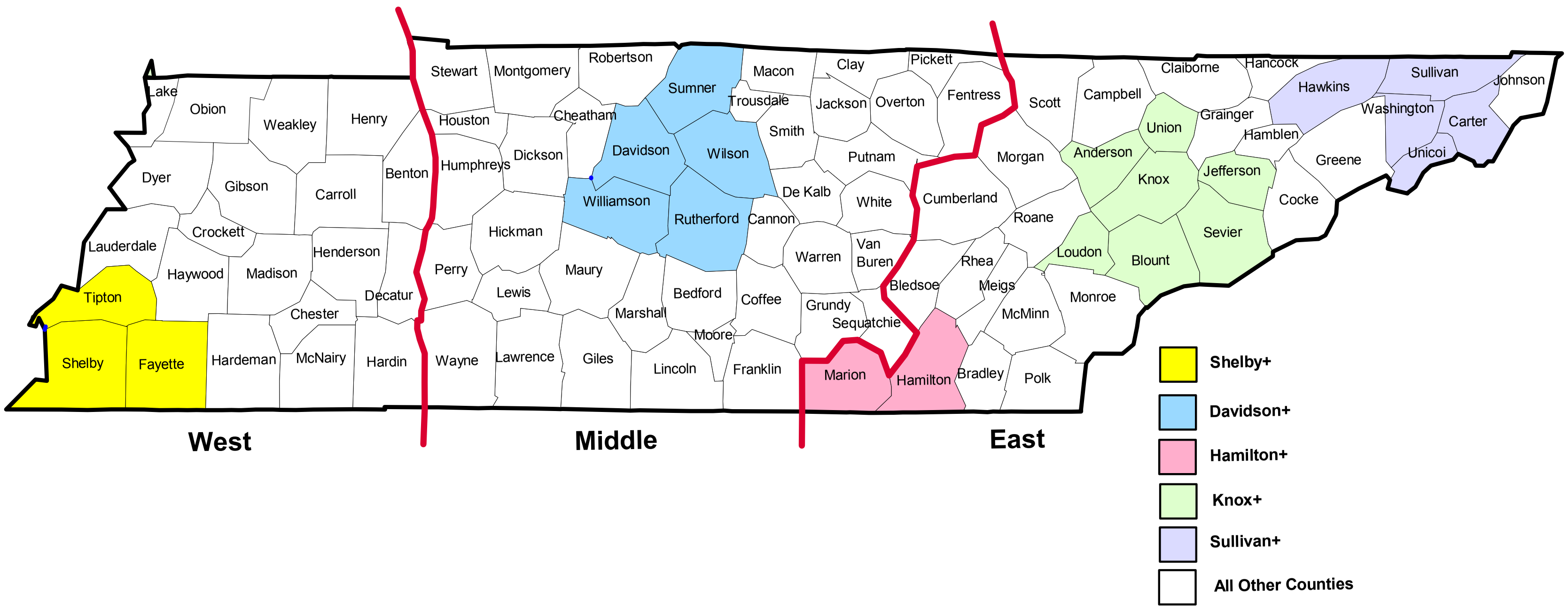

Figure 3-1. Map of the Area Subgroups and the Counties Classified as East, Middle and West Tennessee

3.3.3.1a. Shelby County

Header Section: The input commands and their respective input parameters are shown in Table D1 of the appendix. The output for the runs was specified to be in database format.

Run Section: The Run Section containing the input commands and parameters are shown in Tables D2a through D2f of the appendix. Refueling emissions were not considered in the calculations. West Tennessee average minimum absolute humidity and temperatures (average minimum and average maximum) were used in these runs. Speed values were developed for different roadway classifications based on data obtained from MPO modeling and speed measurement studies. The speeds were developed for Freeway (interstate and freeway) and Arterials (principal arterials, minor arterials and collectors). The speed values used in this study are shown in Table 3-8 in bold under the column "VMT Weighted Mean Speed" for both rural and urban roadway classifications. For Ramps and Local classifications, national default speeds were used. A specific Shelby County VMT mix was used in the modeling listed under the command "VMT FRACTIONS". In this study, it was assumed that the vehicle speed does not change in future years and remains the same throughout the modeling period. Locality specific registration distribution by age (Shelby+) was used and the data were developed as described earlier in the chapter. In accordance with the Memphis MPO Long Range Transportation Plan, it was assumed that an ongoing I/M program exists in the City of Memphis only, and would remain unchanged until the start year of 2020. It was also assumed that a more stringent county-wide I/M program would become effective in the analysis year 2020 and later.

Table 3-8. Summary of Tennessee Highway Speed vs. MOBILE6 Defaults

Roadway Type	TDOT 1999 VMT	Percent of Total (%)	Arterial and Collector Fraction	Average Speed† (mph)	VMT Weighted Mean Speed (mph)	MOBILE6 Default Speeds (mph)	Consolidated Roadway Types
<u>Rural</u>:							
Interstate	25020954	30.6		63.8	**63.8**	36.5	**Freeway**
Principal Arterial	14983302	18.3	0.298*	44.9			
Minor Arterial	15887047	19.5	0.316*	41.9	**40.8****	31.2	**Arterial**
Collector	19412282	23.8	0.386*	37.3			
Local	6353000	7.8		27.2	27.2	**12.9**	**Local**
Ramps				N/A	N/A	N/A***	**Ramps**
<u>Urban</u>:							
Interstate	28244045	29.1		54.9	**54.9**	36.5	**Freeway**
Principal Arterial	28181182	29.1	0.505*	33.5			
Minor Arterial	20810701	21.5	0.373*	33.2	**32.8**	31.2	**Arterial**
Collector	6849480	7.1	0.123*	29.3			
Local	12894000	13.3		20.9	20.9	**12.9**	**Local**
Ramps				N/A	N/A	**34.6**	**Ramps**

N/A – Not Applicable
*Fraction based on the sum of Principal, Minor Arterials and Collectors
**VMT Weighted Mean Speed = (0.298 x 44.9) + (0.316 x 41.9) + (0.386 x 37.3) = 40.8 mph
***Not Applicable since ramp VMT on rural interstates was assumed to be negligible compared to interstate VMT
†See Appendix B.2 for detailed discussion of average speed derivations.

The traditional exhaust I/M program (IDLE) was used to cover pre-1996 model year vehicles and the On-Board Diagnostic (OBD) exhaust I/M program was used for 1996 and newer model year vehicles. In addition, the Evaporative OBD and Gas Cap (GC) evaporative I/M program was assumed to be in place, beginning in 2002, and was applied for 1996 and newer model year vehicles. The earliest model year that was subjected to I/M program was determined based on a 25-year window. For example, if one were to model for analysis year 1999 then the earliest model year subjected to I/M program would be model year 1974. Hence, the "Exemption Age" input parameter was set to 25. Also, an Anti-Tampering Program (ATP) was assumed to be effective starting with year 2019. Other parameters for I/M and ATP program were also chosen based on the Memphis MPO Long Range Transportation Plan. The input parameters for I/M Programs (I/M Programs 1, 2 3,4 and5) are shown in Table D2b through D2f respectively. The I/M program had to be split up into multiple programs (I/M Program 1 and I/M Program 2 and so on) due to reasons such as to avoid double counting of I/M effects, to avoid conflicting dates in I/M start years for Light duty vehicles and heavy duty gasoline vehicles etc. Anti-tampering Program (ATP) input parameters are shown in the run section input parameter tables (Table D2).

Although the last analysis year modeled in the Long Range Plan was 2020, it was assumed that the parameters shown for the analysis year 2020 in the Long Range Plan would remain valid and unchanged for analysis years 2025 and 2030. The Reid vapor pressure used in the model (RVP 7.8) was the same as was used by the Memphis MPO and corresponded to that recommended by ASTM guidance.

Scenario Section: The input commands and their respective input parameters are shown in Table D9 of the appendix. The scenario record was used as a label for individual scenario results. The Calendar Year input parameter was used to identify the calendar year for which emission factors were to be calculated. The runs were modeled for calendar years 1999 through 2010, and for the years 2015, 2020, 2025, and 2030. The Evaluation Month for all the runs was set to July 1st to be representative of the ozone season.

Emission Calculations: Once the input files were prepared, the MOBILE6 model was run with inclusion of all regulations. In order to account for those vehicles that are not under the I/M program but which are registered within the county, it was assumed in the Memphis MPO report that 53.95% of the vehicles were subject to the I/M program and 46.05% were not subject to the I/M program. The same assumption has been used in our calculations. As a result, the model was run twice for each year of analysis (except for years 2020 and thereafter): once with an I/M program and once without. The weighted emissions were calculated using Equation 3.2 with f1 and f2 of 0.5395 and 0.4605 respectively. It should be noted that the factors of 53.95% and 46.05% were not used for years 2020 through 2030 analysis years because of the assumption of a county-wide I/M program.

3.3.3.1b. Tipton and Fayette County

These counties do not have an I/M program or an ATP program. VMT fractions developed for the "Shelby +" group were used for these counties. In addition, these two counties use a fuel with RVP of 9.0 psi. Registration distributions, as mentioned earlier, were developed for each subgroup. Hence they did not change between counties within a subgroup or between urban and rural roadway classifications. Speed values did not change between counties but only between urban and rural roadway classifications. Refueling emissions were not considered in the calculations. The Header and Scenario Sections for all the counties remained the same as that of Shelby county and are shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: The emissions were calculated similar to that for Shelby County except that there was no need for an adjustment for the fraction of vehicles that were subject to and not subject to I/M as shown in Equation 3.3.

3.3.3.2. Davidson+ Subgroup

For the Davidson+ subgroup, most of the input parameters were developed based on the information provided in the Nashville MPO's Long Range Transportation Plan. Refueling emissions were not considered in the calculations. Locality specific VMT mix and temperature values were used and were determined as explained earlier. An RVP of 7.8 psi was used based on the ASTM guidance. The input parameters differed slightly for Davidson County and the other four counties. These differences are tabulated in Table D4a through D4d in the appendix. The Header and Scenario Sections for these counties are as shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: Calculations were made consistent with the Nashville MPO Long Range Transportation Plan, and assumed that 76% of the vehicles were subjected to I/M and 24% were not. Hence, the emission calculations were similar to that of Shelby County using Equation 3.2 with the factors being, 0.76 and 0.24 instead of 0.5395 and

0.4605, respectively. This assumption, however, was not used for the other 4 counties. Hence, the calculations for the other 4 counties were similar to that of Tipton and Fayette counties using Equation 3.3.

3.3.3.3. Hamilton+ Subgroup

The input parameters for the Hamilton+ subgroup are shown in Table D5. Refueling emissions were not considered in the calculations. The calculations are based on a 9.0 psi RVP. Both the counties within this subgroup use the same VMT mix determined for this group. The Header and Scenario Sections for these counties are as shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: Since there is no I/M program in Hamilton+ subgroup, the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

3.3.3.4. Knox+ Subgroup

The input parameters for the Knox+ subgroup are shown in Table D6 of the appendix. While the Knoxville MPO has previously included refueling emissions in its plan, the calculations conducted herein do not include those emissions, in an effort to be consistent with all other counties. The calculations are based on a 9.0 psi RVP. The Header and Scenario Sections for these counties are as shown in Tables D1 and D9 of the appendix, respectively.

Emission Calculations: The calculations are based on no I/M program therefore the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

3.3.3.5. Sullivan+ Subgroup

The input parameters for Sullivan+ subgroup are shown in Table D7 of the appendix. Refueling emissions were not considered in the calculations. The calculations are based on a 9.0 psi RVP. The Header and Scenario Sections for these counties are as shown in Table D1 and D9 of the appendix, respectively.

Emission Calculations: The calculations are based on no I/M program therefore the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.

3.3.3.6. All Other Counties

The input parameters for all other counties are shown in Table D8 of the appendix. The only differences in the input parameters between the counties within this subgroup were the min/max temperatures and the absolute humidity values depending on the region (east, middle or west) where the county is located, and in some cases a difference in the registration distribution. Most counties used a registration distribution that was developed for this subgroup. However, for those counties whose interstate traffic comprised more than 50% of the total DVMT, the national default registration distribution was used, as discussed earlier. Counties with greater than 50% interstate DVMT include Roane, Cumberland and Campbell Counties in the East Tennessee region;

Putnam, Smith, Robertson and Coffee Counties in the Middle Tennessee region; and Henderson and Haywood Counties in the West Tennessee region. They are shown in italics in Table C1. The calculations are based on a 9.0psi RVP and no I/M program. The Header and Scenario Sections for these counties are as shown in Table D1 and D9 of the appendix, respectively.

Emission Calculations: Since the calculations are based on no I/M program therefore the emission calculations remain similar to that of Tipton and Fayette Counties using Equation 3.3.