Texas A&M Transportation Institute

MOVES3 On-Road Trend Emissions Inventories for 1990 and 1999 through 2060

FINAL Report

Prepared for the Texas Commissions on Environmental Quality

April 2023

Texas A&M Transportation Institute

FINAL REPORT

Grant Number: 582-21-10369

Sub-Task 5 – Draft and Final Reports

DATE:	**April 18, 2023**
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Acronym	Definition
AADT	Annual Average Daily Traffic
AERR	Air Emissions Reporting Requirements
APU	Auxiliary Power Unit
ATR	Automatic Traffic Recorder
AVFT	Alternate Vehicle and Fuel Technology
BPA	Beaumont–Port Arthur
CAA	Clean Air Act
CDB	County Database
CFR	Code Of Federal Regulations
CG	Conventional Gasoline
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO2	Carbon Dioxide
COG	Council Of Governments
CT	Combination Trucks
DFW	Dallas-Fort Worth
EI	Emissions Inventory
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ERG	Eastern Research Group
FHWA	Federal Highway Administration
FMVCP	Federal Motor Vehicle Control Programs
GAD	Grant Activity Description
GUI	Graphical User Interface
GVW	Gross Vehicle Weight
HAP	Hazardous Air Pollutants
HGB	Houston-Galveston-Brazoria
HPMS	Highway Performance Monitoring System
I/M	Inspection And Maintenance
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
MRS	Moves Run Specification
MSA	Metropolitan Statistical Area
MTBE	Methyl Tertiary Butyl Ether
N_2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards

NEI	National Emissions Inventory
NH_3	Ammonia
NOX	Oxides Of Nitrogen
OBD	On-Board Diagnostics
ONI	Off-Network Idling
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
QAPP	Quality Assurance Project Plans
RFG	Reformulated Gasoline
RIF	Road Idle Fraction
RIFCREC	Roadway Inventory Functional Classification Record
RVP	Reid Vapor Pressure
SAFE	Safer Affordable Fuel Efficient
SHEI	Source Hours Extended Idling
SHI	Source Hours Idling
SHO	Source Hours Operating
SHP	Source Hours Parked
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
ST	Single Unit Trucks
SUT	Source Use Type
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TOD	Time Of Day
TSDC	Texas State Data Center
TTI	Texas A&M Transportation Institute
VHT	Vehicle Hour Travelled
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compounds
VPGF	Vehicle Types Population Growth Factor

EXECUTIVE SUMMARY

The Texas Commission on Environmental Quality (TCEQ) is continuing the process of responding to current, newly implemented, and future U.S. Environmental Protection Agency (EPA) air quality standards. This ongoing air quality improvement process involves many decisions concerning the approach to attainment of the standards, including design and implementation of various air pollutant emissions control programs. One helpful tool is a current and complete assessment of the trends in on-road mobile source emissions. Since trend inventories, as have been sponsored by TCEQ in the past, are produced for all counties and for many years, the practical approach is to use a more aggregate method than, for example, is used for the more detailed State Implementation Plan (SIP) inventories (i.e., detailed travel model link-based inventories for metropolitan counties with available travel demand models). Since the EPA released a major revision of its on-road emissions modeling tool, Motor Vehicle Emission Simulator (MOVES)[1], in November 2020 (MOVES2014 replaced by MOVES3), a new set of emissions trend inventories is needed. These new trend inventories will characterize emissions reflecting the effects of newly promulgated emissions and fuel economy standards included in MOVES.

Such emissions trends assessments are needed to respond to legislative questions, understand past performance, and to determine future requirements. TCEQ enlisted a team of Texas A&M Transportation Institute (TTI) researchers to produce this new set of trend emissions inventories for on-road mobile sources.

To capture the effects of the early control programs implemented in response to the federal Clean Air Act (CAA) Amendments of 1990, along with the substantial effects of fleet turnover to the newest federal motor vehicle tailpipe certification standards and fuel economy standards, the trend inventories were developed for all calendar years available in MOVES – 1990 and 1999 through 2060. MOVES does not include the years 1991 through 1998 so no inventories were produced for these years. Because the trend inventories may be used for many purposes, they were also developed for every Texas county and include estimates for both summer weekday and annual emissions.

As displayed in Table 1, TTI developed summer weekday emissions inventory (EI) estimates of criteria air pollutants (CAPs) and CAP precursors, greenhouse gases

[1] The study uses the version 3.0.3 version of MOVES and default MOVES3 database, movesdb20220105.

(GHGs), as well as annual emissions inventory (EI) estimates of these same emissions categories, plus hazardous air pollutants (HAPs).

Table 1. EI Type and Pollutants Modeled

Area	EI Type[1]	Pollutants
All 254 Texas Counties	Annual	CAPs, CAP precursors, GHGs, and HAPs
All 254 Texas Counties	Summer Weekday	CAPs, CAP precursors, and GHGs

[1] "Annual" represents the calendar year totals for all counties. "Summer" represents June, July, and August. "Weekday" represents the average Monday through Friday.

Summer weekday and annual emission inventories were estimated using 24-hour (daily) Highway Performance Monitoring System (HPMS) based vehicle activity estimates and daily emission rates produced from MOVES "Portion of Week" inventory mode output.

Both summer weekday and annual vehicle miles traveled (VMT) for all 254 Texas counties were estimated using the statewide HPMS-based method, which uses HPMS data from the Texas Department of Transportation (TxDOT) as the basis of historic-year and forecasted future-year on-network vehicle activity. For the summer weekday scenario, seasonal adjustment factors estimated from automatic traffic recorder (ATR) data were applied to estimate summer season adjusted VMT. In both scenarios, the HPMS data were post-processed to estimate hourly directional, HPMS link-level VMT, and operational speeds for the emission calculations[2]. The hourly HPMS link-level VMT was aggregated to 24-hour (daily) VMT for emission calculations. For the annual scenario, the 24-hour VMT estimated from the annual average daily traffic (AADT) was multiplied by 365 to calculate the annual VMT.

For off-network activity, the 24-hour off-network activity was estimated using the TTI EI off-network activity estimation method with vehicle operating hours data (also known as vehicle hours traveled [VHT]), vehicle type populations, combination long-haul truck hotelling, and other factors. This off-network activity is off-network idling (ONI) hours, source hours parked (SHP), starts, source hours extended idling (SHEI), and auxiliary power unit (APU) hours—where SHEI and APU hours are components of hotelling hours for combination long-haul trucks. For the annual scenario, the annual

[2] Although only daily (24-hour aggregate) and annual level activity estimates were used in the emissions calculations for this project, TTI employed a standard time period-based activity estimation approach which retained greater temporal and spatial detail (Hourly HPMS Link Speeds, Hourly HPMS Link VMT, etc.) than needed. Per the trends EIs methodology, aggregations of these more detailed activity estimations were used in the EI calculations.

average daily off-network activity was multiplied by 365 to calculate the annual off-network vehicle activity.

TTI prepared all 16,002 (254 Texas counties with 63 total analysis years) MOVES inventory mode county databases (CDB) as part of the deliverables in Task 3. In each analysis year, 254 Texas counties have been grouped into 36 to 44 county groups based on local fuel characteristics, TxDOT district level, and inspection and maintenance (I/M) programs. In each county group, one representative county was selected to perform the "Portion of Week" inventory mode MOVES runs. All counties in the same county group shared the same emission rates post-processed from the representative county MOVES run[3]. With the grouping method, a total of 2,749 representative CDBs for MOVES "Portion of Week" inventory mode runs were conducted using local input data (from the weekday/weekend EI activity data and various conversion factors) and some MOVES default input data. The MOVES "Portion of Week" inventory mode runs aggregate hourly results to output total emissions and activity over a 5-day work week portion and a typical 2-day weekend portion for each month of the calendar year. The summer weekday rates were calculated by scaling the emission and activity from typical weekdays from June, July, and August to the entire month based on the number of weekdays in that month and summing the emission and activity to get the summer weekday scenario emission and activity, which in turn were used to calculate the summer weekday rates (summer weekday emissions/summer weekday activity). Annual average daily rates were computed using the emission and activity from typical weekdays and weekends from each of 12 months to the entire month based on the number of weekdays and weekends in that month and summing the emission and activity to get the annual emission and activity, which in turn were used to calculate the annual average daily rates (annual emissions/annual activity).

Post-processing was performed using MOVES activity and emission output to produce the on-network and off-network emission rates in terms of mass per vehicle activity unit (i.e., mass/mile, mass/SHP, mass/start, mass/ONI hour, mass/SHEI, mass/APU hour). Total Gaseous Hydrocarbons, Benzene, Ethanol, Non-Methane Hydrocarbons, and Volatile Organic Compounds (VOC) off-network emissions for gasoline-powered vehicles were computed using the mass/SHP factor as gasoline powered vehicles emit

[3] Grouping method helped to significantly reduce the total time for MOVES run from 64,008 total hours (2 hours per run per scenario) to 5,498 hours (2 hours per run) while not losing resolution on emission rates with local fuel parameters.

these pollutants even when the engine is turned off. For idling while off-network (not including hotelling activity), other pollutant and fuel type combination emissions were computed using the mass/ONI rates.

Since MOVES does not include the effects of the Texas Low Emissions Diesel (TxLED) program, adjustments were applied to incorporate TxLED effects in the 110 central and eastern counties in the program. The final rates tables consist of VMT based rates which were by road type for the on-network emissions calculations and off-network activity categorized rates which were for the off-network emissions calculations.

The summer weekday and annual emission inventories were produced by county for each analysis year using the MOVES inventory output-based emissions rates and the activity estimates developed based on the methodologies described in the following sections. The aggregate emissions calculations fall into two categories: VMT-based emissions calculations and off-network activity based emissions calculations. The VMT-based emissions calculations use the 24-hour (daily) summer weekday and annual MOVES road type and source use type (SUT)/fuel type VMT and summer weekday/annual average daily aggregated VMT-based emission rates to estimate VMT based emissions at the MOVES road type and SUT/fuel type level. The off-network emissions calculations use the 24-hour (daily) summer weekday and annual off-network activity (SHP, starts, ONI, SHEI, and APU hours by SUT/fuel type) and summer weekday/annual average daily aggregated off-network activity-based emission rates to estimate emissions at the county level by SUT/fuel type.

The 24-hour summer weekday EIs and annual EIs were estimated by MOVES SUT and fuel type combination (SUT/fuel type or vehicle type), and by roadway class which includes an off-network category. This EI analysis was performed for all 254 Texas counties.

This analysis included both summer weekday and annual emission estimates for VOC, carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur dioxide (SO_2), ammonia (NH_3), carbon dioxide (CO_2), particulate matter (PM) with an aerodynamic diameter equal to or less than 2.5 microns ($PM_{2.5}$), and PM with an aerodynamic diameter equal to or less than 10 microns (PM_{10}); and annual estimates for HAPs, which included: benzene, ethanol, naphthalene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and diesel PM plus diesel exhaust organic gases. Emission summaries by the on-road mobile source emissions processes available in MOVES were included (the area source refueling emissions processes in MOVES were excluded). Table 2 shows a brief summary of the statewide summer weekday VMT and emissions for VOC, CO, NO_X, and CO_2 (more detailed summaries are provided in the report).

Table 2. Snapshot of Statewide Summer Weekday VMT and Emissions for Years 1990 through 2060 (Tons/Day).

Year	VMT	VOC	CO	NO_X	CO_2
1990	468,690,876	1,417	25,031	2,944	381,491
2000	632,191,513	1,113	16,374	3,200	437,686
2010	682,191,243	472	6,634	1,458	466,269
2020	756,871,893	177	3,626	499	454,793
2030	975,930,374	121	2,667	308	467,892
2040	1,107,378,724	100	1,969	283	485,023
2050	1,250,439,335	103	2,017	306	539,237
2060	1,381,554,685	113	2,208	332	594,170

1 INTRODUCTION

The TCEQ works with local planning districts, the Texas Department of Transportation (TxDOT), and the TTI to provide on-road mobile source emission inventories (EI) of air pollutants. TxDOT typically funds transportation conformity determinations required under 40 Code of Federal Regulations (CFR) Part 93. The TCEQ funds mobile source inventory work in support of federal CAA requirements, such as the attainment of the National Ambient Air Quality Standards (NAAQS), as well as the control of hazardous air pollutants (HAPs).

1.1 Objective

In November 2020, the EPA released the latest version of the Motor Vehicle Emission Simulator model (MOVES3). Thus, a new set of trend inventories and associated MOVES input CDBwere needed to characterize the transition to MOVES3, respond to data requests, assess past performance, and determine future requirements.

The objective was to develop a comprehensive set of MOVES model-based CDB files for all 254 Texas counties and use them in the production of new, relatively up-to-date on-road mobile source trend emissions inventories. Unlike other Texas on-road mobile inventories that have been developed with a different method to meet the specific analysis requirements for SIP development or EPA reporting, the trend inventories documented in this report are ideal for tracking on-road mobile activity and emissions trends from county-to-county and year-to-year.

TTI developed a set of 1990 and 1999 through 2060 on-road mobile trend inventories for criteria air pollutants (CAPs), CAP precursors, greenhouse gases (GHGs)[4], and hazardous air pollutants (HAPs) to support air quality planning activity. The trend inventories begin with the analysis year 1990 to capture the effects of control programs implemented due to the 1990 Clean Air Act (CAA) Amendments. TTI developed the trend inventories through the year 2060 to capture the substantial effects of fleet turnover and the newest Federal Motor Vehicle Control Program certification standards, which are Tier 3 regulations for light-duty vehicles that phase in from the 2017 through 2025 model years. The scope of the trend inventories included:

[4] TTI included GHG pollutants such as CO_2, CH_4, N_2O in the analysis to be inclusive of various Texas state and local agencies using the results in their air quality and transportation planning activities.

- Every Texas county;
- Analysis years 1990 and 1999 through 2060 (MOVES does not allow the years 1991 through 1998 to be analyzed);
- CAPs, CAP precursors, GHGs, and HAPs;
- CDBs for all Texas counties applicable to the calendar year, seasons, months, and MOVES day-types; and
- Estimates for summer weekday and annual emissions.

1.1.1 Development and Production of Trend Emissions Inventories

TTI developed inventories based on 24-hour highway performance monitoring system (HPMS) average summer weekday and annual emissions estimates and CDBs for each of the 254 Texas counties, for 1990 and each year inclusive from 1999 through 2060. The level of detail in the final emissions estimates was aggregated emissions by county, fuel type, and source use type.

- The various MOVES3 parameters and other inventory development components described below were used directly or estimated as noted, consistent with the selected season and day type combinations. TTI produced these inventories based on the following scope, agreed upon in consultation with the TCEQ project manager:
    - Used the most recent version of the EPA's on-road emissions model, MOVES3, released in November 2020, as the emissions factor model for developing inventories detailed in this task.
    - The CAPs, CAP precursors, and other pollutants (see Table 3) included were: VOC, CO, NO_X, SO_2, NH_3, CO_2, methane (CH_4), nitrous oxide (N_2O), PM_{10}, and $PM_{2.5}$. The HAPs (see
    - Table 4) included were benzene, ethanol, naphthalene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and diesel particulate matter plus diesel exhaust organic gases.

Table 3. List of CAPs and CAP Precursors Included in the Annual Inventory Runs of Trend Inventories

MOVES Pollutant ID	Pollutant Name
2	CO
3	NO_X
30	NH_3
31	SO_2
87	VOC
90	Atmospheric CO_2
100	Primary Exhaust PM_{10} – Total
106	Primary PM_{10} – Brakewear Particulate
107	Primary PM_{10} – Tirewear Particulate
110	Primary Exhaust $PM_{2.5}$ – Total
116	Primary $PM_{2.5}$ – Brakewear Particulate
117	Primary $PM_{2.5}$ – Tirewear Particulate
98	CO_{2eq} (which includes CH_4(5), CO_2(90), and N_2O(6))

Table 4. List of HAPs included in Annual Inventory Runs of Trend Inventories

Category	MOVES Pollutant ID		Pollutant Name[2]	National Emissions Inventory (NEI) Pollutant Code
Gaseous HC	20		Benzene	71432
	21		Ethanol	
	24		1,3-Butadiene	106990
	25		Formaldehyde	50000
	26		Acetaldehyde	75070
	27		Acrolein	107028
	23		Naphthalene	91203
Polycyclic Aromatic Hydrocarbon (PAH)	**Gas**	**PM**		
	185	23	Naphthalene	91203

- Modeled the MOVES3 pollutant processes (see Table 5) of running exhaust, crankcase running exhaust, start exhaust, crankcase start exhaust, extended idle exhaust, crankcase extended idle exhaust, auxiliary power exhaust, evaporative permeation, evaporative fuel vapor venting, evaporative fuel leaks, brakewear, and tirewear.

Table 5. MOVES Emission Processes included in the Trend Inventories

MOVES Process ID	Emission Process Name
1	Running Exhaust
2	Start Exhaust
9	Brakewear
10	Tirewear
11	Evap Permeation
12	Evap Fuel Vapor Venting
13	Evap Fuel Leaks
15	Crankcase Running Exhaust
16	Crankcase Start Exhaust
17	Crankcase Extended Idle Exhaust
90	Extended Idle Exhaust
91	Auxiliary Power Exhaust

- Used temperature, humidity, and barometric pressure data provided by TCEQ.
  - The latest available 2019 meteorological data (consistent with the Texas 2020 Air Emissions Reporting Rule EIs) was used for all analysis years. Local data for each of the twelve months (where winter is December, January, and February, spring is March, April, and May, summer is June, July, and August, and fall is September, October, and November) were utilized and organized into the appropriate MOVES input table (“ZoneMonthHour”) for use with all 254 counties.
  - The annual average barometric pressure (entered in the MOVES “county” table) from 2019 meteorological data was used for all analysis years.
- Used VMT mixes consistent with the EPA MOVES source use types.
  - The time of day (TOD) VMT mixes by TxDOT district were categorized by MOVES roadway type for the years 1990 and 2000 through 2060, and produced in 5-year intervals. No Roadtype (No_RT) VMT mixes[5]

[5] No_RT VMT mixes are VMT mixes used to distribute raw vehicle population data to source-type based vehicle populations where no roadtype information is associated with the vehicles for the purpose of off-network vehicle activity and emissions estimation.

by TxDOT district were developed independent of MOVES roadway type for the VMT mix years.

- Table 6 shows the correlation between VMT mix years and analysis years.

Table 6. VMT Mix Year/Analysis Year Correlations

VMT Mix Year	Analysis Years
1990	1990
2000	1999 through 2002
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 through 2052
2055	2053 through 2057
2060	2058 through 2060

- Used locality-specific MOVES age distributions input for historical and future years based on available and suitable local vehicle registration data in conjunction with MOVES default age distributions as needed.
  - The 2018 local age distribution data was used for all analysis years. Age distributions for all source types (except refuse trucks, motor homes, and buses) were estimated using Texas Department of Motor Vehicles (TxDMV) data; the age distribution for refuse trucks, motor homes, and buses comes from the MOVES defaults (MOVES "sourcetypeagedistribution" table) for the analysis year.
- Used fuel parameter inputs as defined in 40 CFR Section 80.27.
- Modeled federal- and state-regulated summer Reid vapor pressure (RVP) levels consistent with assumptions allowed for refiner compliance safety margins.
- Modeled the effects of the oxygenated fuel program for El Paso.

- Modeled expected actual historical sulfur levels consistent with federally regulated gasoline and diesel sulfur levels and used MOVES defaults of six parts per million (ppm) for future years.
- Modeled reformulated gasoline (RFG) for the four Dallas-Fort Worth (DFW) and the eight Houston-Galveston-Brazoria (HGB) ozone nonattainment counties that use RFG. By TTI and TCEQ project manager consultation, only the current twelve (12) RFG counties under existing law were modeled.
- Modeled the effects of all the federal motor vehicle control programs that are included as defaults in the MOVES model.
  - For each analysis year and season, the fuel supply consisted of one conventional gasoline formulation and one diesel formulation.
  - The application of summer fuel formulations in the summer weekday emission rates was via month ID where MOVES month ID "7" (July) was used to represent the summer season. For the annual emissions analysis the fuel formulations were input by month (or month ID, where 1, 2, 3... is January, February, March...), as follows:
    - Summer fuel formulations for month IDs 5, 6, 7, 8, and 9;
    - Winter fuel formulations for month IDs 1, 2, 3, 11, and 12;
    - Shoulder fuel formulations for month IDs 4 and 10.
- Modeled the Austin-Round Rock, DFW, HGB, and El Paso inspection and maintenance (I/M) programs using the latest available I/M database and updated compliance factors.

- Incorporated the following parameters, requirements, or considerations when modeling:
  - Developed VMT by county for future years using historical TxDOT VMT data and U.S. Census population statistics and projections, consistent with the current practice for statewide HPMS-based method applications.
  - Developed final emissions estimates aggregated by county, source use type, and fuel type, based on 24-hour HPMS activity.
  - Used 24-hour VMT data to develop the EI.

- For the summer weekday emission inventories, modeled average summer weekday (i.e., Monday through Friday) emissions rates, coupled with average summer weekday activity.
- Adjusted activity levels for the summer season (June through August) and average weekday, Monday through Friday.
- Used year-specific TxLED adjustment factors developed using the benefits information described in the EPA Memorandum on TxLED Fuel Benefits. TTI developed NOx adjustment factors using reductions of 4.8 percent for 2002-and-newer model-year vehicles and 6.2 percent for 2001-and-older model-year vehicles.

TTI employed the methods for inventory development, as documented in the project grant activity description (GAD), in consultation with the TCEQ project manager.

1.2 Summary of Results

Table 7 summarizes the average summer (June through August) weekday (Monday through Friday) emissions, VMT, and yearly human population estimates for the entire state, whereas Table 8 summarizes the same estimates but for an annual timeframe.

Table 7. Statewide Average Summer Weekday VMT and Emissions (Tons/Day) and Yearly Human Population Trends Summary.

Year	CO_2	CO	NH_3	NO_x	$PM_{2.5}$[1]	SO_2	VOC	VMT	Population[2]
1990	381,491	25,031	18.6	2,944	136.0	129.42	1,417	468,690,876	17,044,714
1999	423,201	17,299	40.9	3,265	99.7	56.60	1,191	605,771,530	20,044,141
2000	437,686	16,374	42.0	3,200	95.0	50.70	1,113	632,191,513	20,944,499
2001	431,570	15,106	40.9	3,044	88.7	49.93	1,021	625,183,109	21,319,622
2002	433,055	14,091	39.9	2,880	83.2	50.05	952	628,841,270	21,690,325
2003	437,699	13,068	38.8	2,709	82.1	50.61	886	635,574,295	22,030,931
2004	457,965	12,095	39.2	2,586	82.0	40.11	827	666,351,268	22,394,023
2005	468,550	10,909	38.7	2,402	80.1	27.86	753	682,388,357	22,778,123
2006	473,611	10,092	37.7	2,173	77.9	25.47	697	689,833,562	23,359,580
2007	483,173	9,099	36.9	1,988	70.8	8.65	635	703,818,022	23,831,983
2008	467,472	7,792	33.8	1,785	62.7	8.43	568	681,395,218	24,309,039
2009	461,638	7,043	32.1	1,617	56.4	8.35	514	675,626,723	24,801,761
2010	466,269	6,634	31.1	1,458	50.9	8.43	472	682,191,243	25,145,561
2011	470,482	6,110	30.5	1,304	43.2	6.88	420	691,618,753	25,567,291
2012	468,199	5,652	29.2	1,168	37.6	6.85	376	690,771,678	25,996,722

Year	CO_2	CO	NH_3	NO_x	$PM_{2.5}$[1]	SO_2	VOC	VMT	Population[2]
2013	481,888	5,435	28.4	1,091	34.3	6.95	345	712,354,930	26,433,242
2014	472,542	5,074	26.5	960	29.1	7.05	309	708,005,034	26,876,429
2015	494,473	5,081	26.7	886	27.6	6.93	296	751,823,585	27,326,193
2016	509,491	4,896	26.7	820	26.5	6.94	276	787,698,951	27,782,691
2017	506,758	4,622	25.8	738	25.0	6.16	253	795,068,685	28,245,982
2018	514,147	4,480	25.6	691	23.7	6.19	237	821,425,425	28,716,123
2019	515,178	4,308	25.3	622	20.3	4.65	218	839,324,869	29,193,268
2020	454,793	3,626	22.1	499	16.1	2.75	177	756,871,893	29,677,668
2021	505,903	3,887	24.9	515	16.3	3.04	186	863,434,149	30,168,926
2022	501,753	3,742	24.8	469	15.2	3.02	176	875,617,791	30,667,390
2023	497,743	3,586	24.8	437	14.6	2.98	167	887,886,896	31,172,832
2024	492,216	3,455	24.9	406	14.0	2.95	158	900,237,543	31,685,234
2025	486,988	3,324	25.0	380	13.3	2.91	152	912,681,501	32,204,920
2026	482,086	3,176	25.0	357	12.6	2.88	140	925,188,500	32,730,748
2027	477,113	3,067	25.2	343	12.2	2.86	135	937,776,327	33,263,027
2028	472,794	2,920	25.4	331	11.8	2.82	128	950,426,136	33,801,104
2029	469,990	2,780	25.6	319	11.7	2.80	124	963,150,745	34,345,157
2030	467,892	2,667	25.9	308	11.5	2.79	121	975,930,374	34,894,452
2031	466,464	2,561	26.2	298	11.4	2.78	117	988,774,703	35,449,059
2032	466,240	2,461	26.2	292	11.2	2.78	114	1,001,668,944	36,008,470
2033	466,305	2,358	26.5	287	11.2	2.77	111	1,014,616,023	36,572,564
2034	467,194	2,269	26.8	284	11.2	2.78	109	1,027,631,571	37,142,038
2035	469,031	2,193	27.1	283	11.2	2.79	107	1,040,707,944	37,716,495
2036	471,246	2,126	27.5	282	11.3	2.80	104	1,053,861,463	38,296,865
2037	474,021	2,070	27.8	281	11.2	2.82	103	1,067,098,250	38,883,894
2038	477,490	2,025	28.1	282	11.3	2.83	101	1,080,416,734	39,477,164
2039	480,979	1,993	28.4	283	11.4	2.85	101	1,093,844,899	40,078,056
2040	485,023	1,969	28.8	283	11.5	2.88	100	1,107,378,724	40,686,496
2041	489,335	1,954	29.1	285	11.5	2.90	100	1,121,003,650	41,303,005
2042	493,992	1,946	29.5	286	11.6	2.93	99	1,134,771,897	41,928,733
2043	498,999	1,944	29.8	288	11.7	2.96	99	1,148,663,825	42,564,184
2044	504,218	1,948	30.2	291	11.9	2.99	100	1,162,707,483	43,209,911
2045	509,626	1,957	30.5	293	12.0	3.02	100	1,176,897,717	43,866,965
2046	515,183	1,968	30.9	295	12.1	3.05	100	1,191,254,309	44,535,432
2047	520,967	1,969	31.3	298	12.2	3.09	101	1,205,772,298	45,216,833
2048	526,930	1,980	31.7	301	12.3	3.12	102	1,220,482,183	45,911,304
2049	533,036	1,998	32.1	303	12.4	3.16	103	1,235,375,638	46,619,758
2050	539,237	2,017	32.4	306	12.6	3.19	103	1,250,439,335	47,342,105

Year	CO_2	CO	NH_3	NO_x	$PM_{2.5}$[1]	SO_2	VOC	VMT	Population[2]
2051	544,644	2,034	32.8	309	12.7	3.23	104	1,263,551,248	47,905,871
2052	550,102	2,051	33.1	311	12.8	3.26	105	1,276,662,815	48,469,636
2053	555,578	2,069	33.5	314	12.9	3.29	106	1,289,774,666	49,033,402
2054	561,055	2,087	33.8	316	13.0	3.32	107	1,302,886,335	49,597,168
2055	566,547	2,106	34.1	319	13.1	3.36	108	1,315,996,113	50,160,933
2056	572,049	2,126	34.5	322	13.2	3.39	109	1,329,107,408	50,724,699
2057	577,568	2,147	34.8	324	13.3	3.42	110	1,342,219,217	51,288,465
2058	583,101	2,167	35.2	327	13.4	3.46	111	1,355,330,819	51,852,230
2059	588,636	2,188	35.5	329	13.5	3.49	112	1,368,442,806	52,415,996
2060	594,170	2,208	35.8	332	13.6	3.52	113	1,381,554,685	52,979,762

[1] PM estimates are MOVES-based only (i.e., no re-suspended dust from roadways is included).
[2] 1990 and 1999 population data retrieved from https://www.tsl.texas.gov/ref/abouttx/census.html, 2000 through 2009 population data retrieved from https://www.census.gov/programs-surveys/popest/data/tables.2009.html, 2010 through 2060 population projection retrieved from https://demographics.texas.gov/data/TPEPP/Projections/

Table 8. Statewide Annual VMT and Emissions (Tons/Year) and Yearly Population Trends Summary.

Year	CO_2	CO	NH_3	NO_x	$PM_{2.5}$[1]	SO_2	VOC	VMT (million miles)	Population[2]
1990	124,571,117	7,933,542	6,377	1,019,741	42,647	42,090	466,665	160,779	17,044,714
1999	136,733,655	5,284,075	14,115	1,128,618	31,288	19,050	386,414	207,883	20,044,141
2000	141,273,296	4,954,706	14,481	1,106,952	29,850	17,444	362,840	216,964	20,944,499
2001	139,205,349	4,554,474	14,099	1,051,667	27,865	17,161	332,297	214,645	21,319,622
2002	139,539,052	4,234,532	13,742	993,313	26,124	17,180	309,067	215,872	21,690,325
2003	140,899,756	3,910,318	13,389	934,192	25,752	17,354	287,444	218,208	22,030,931
2004	147,298,053	3,617,900	13,517	889,205	25,690	13,468	267,949	228,718	22,394,023
2005	150,626,421	3,256,466	13,320	824,019	25,078	8,900	243,393	234,231	22,778,123
2006	152,215,403	3,008,718	12,977	746,106	24,399	8,155	224,761	236,852	23,359,580
2007	155,235,060	2,700,668	12,672	681,563	22,192	2,833	202,770	241,658	23,831,983
2008	150,140,103	2,303,541	11,622	611,421	19,651	2,730	179,024	233,952	24,309,039
2009	148,226,715	2,073,015	11,011	553,043	17,699	2,676	161,049	231,976	24,801,761
2010	149,670,543	1,950,916	10,669	498,831	15,972	2,728	147,520	234,261	25,145,561
2011	150,952,773	1,791,416	10,446	445,565	13,585	2,243	130,978	237,443	25,567,291
2012	150,210,800	1,650,210	10,013	398,828	11,864	2,234	116,976	237,172	25,996,722
2013	154,548,031	1,580,348	9,711	372,076	10,831	2,268	107,210	244,536	26,433,242
2014	151,487,829	1,491,309	9,063	327,435	9,216	2,347	95,422	243,000	26,876,429
2015	158,516,709	1,480,884	9,138	301,406	8,763	2,276	91,101	258,122	27,326,193
2016	163,329,249	1,419,241	9,116	278,859	8,431	2,315	85,145	270,522	27,782,691
2017	162,421,049	1,338,040	8,799	251,011	7,940	2,108	78,212	272,981	28,245,982

Year	CO_2	CO	NH_3	NO_x	$PM_{2.5}$[1]	SO_2	VOC	VMT (million miles)	Population[2]
2018	164,796,398	1,298,783	8,727	235,049	7,556	2,073	73,640	282,037	28,716,123
2019	165,126,479	1,243,174	8,618	211,107	6,534	1,541	67,777	288,227	29,193,268
2020	145,717,512	1,042,875	7,543	169,087	5,190	891	55,029	259,868	29,677,668
2021	162,109,623	1,115,739	8,489	174,486	5,278	988	58,065	296,500	30,168,926
2022	160,759,854	1,072,983	8,449	159,155	4,932	979	55,092	300,681	30,667,390
2023	159,445,749	1,027,347	8,444	148,126	4,747	967	52,481	304,890	31,172,832
2024	157,672,156	989,575	8,460	137,231	4,572	956	49,979	309,127	31,685,234
2025	155,997,777	951,563	8,501	128,626	4,356	946	48,055	313,396	32,204,920
2026	154,423,942	908,628	8,504	120,888	4,140	936	44,672	317,686	32,730,748
2027	152,838,641	877,652	8,569	116,171	4,011	926	43,246	322,003	33,263,027
2028	151,461,000	836,062	8,629	111,794	3,891	915	41,380	326,342	33,801,104
2029	150,563,404	797,217	8,716	107,773	3,864	910	40,331	330,705	34,345,157
2030	149,891,668	765,620	8,810	104,136	3,794	906	39,403	335,087	34,894,452
2031	149,438,036	735,250	8,905	100,436	3,749	903	38,362	339,491	35,449,059
2032	149,362,496	707,927	8,924	98,694	3,717	902	37,641	343,912	36,008,470
2033	149,380,881	679,526	9,011	97,047	3,709	900	36,762	348,350	36,572,564
2034	149,666,895	655,235	9,120	96,047	3,706	902	36,090	352,811	37,142,038
2035	150,253,031	634,711	9,231	95,485	3,719	905	35,570	357,293	37,716,495
2036	150,963,623	616,715	9,343	95,140	3,735	909	34,958	361,801	38,296,865
2037	151,851,632	601,528	9,456	94,735	3,710	914	34,576	366,337	38,883,894
2038	152,953,660	589,431	9,560	95,321	3,738	919	34,147	370,901	39,477,164
2039	154,073,027	580,979	9,674	95,437	3,765	926	33,950	375,502	40,078,056
2040	155,368,588	574,829	9,789	95,630	3,794	934	33,775	380,139	40,686,496
2041	156,747,893	571,238	9,906	96,105	3,825	942	33,728	384,807	41,303,005
2042	158,235,690	569,450	10,026	96,669	3,857	951	33,707	389,523	41,928,733
2043	159,834,643	569,221	10,137	97,344	3,892	959	33,732	394,282	42,564,184
2044	161,505,416	570,782	10,259	98,059	3,929	969	33,874	399,092	43,209,911
2045	163,236,122	573,491	10,383	98,864	3,967	979	34,071	403,952	43,866,965
2046	165,014,392	577,164	10,509	99,689	4,005	990	34,173	408,869	44,535,432
2047	166,866,044	577,928	10,636	100,531	4,042	1,001	34,441	413,841	45,216,833
2048	168,773,485	581,389	10,766	101,434	4,081	1,012	34,658	418,878	45,911,304
2049	170,726,054	586,714	10,896	102,392	4,123	1,024	34,996	423,978	46,619,758
2050	172,709,256	592,390	11,028	103,376	4,164	1,036	35,270	429,136	47,342,105
2051	174,440,175	597,408	11,144	104,205	4,199	1,046	35,589	433,631	47,905,871
2052	176,187,077	602,592	11,259	105,045	4,236	1,057	35,832	438,126	48,469,636
2053	177,939,641	607,930	11,376	105,895	4,273	1,067	36,177	442,621	49,033,402
2054	179,693,157	613,354	11,491	106,739	4,309	1,078	36,517	447,115	49,597,168

Year	CO_2	CO	NH_3	NO_x	$PM_{2.5}$[1]	SO_2	VOC	VMT (million miles)	Population[2]
2055	181,451,650	618,807	11,607	107,591	4,346	1,088	36,858	451,609	50,160,933
2056	183,213,088	624,852	11,722	108,459	4,383	1,099	37,207	456,104	50,724,699
2057	184,980,048	630,893	11,837	109,323	4,420	1,109	37,556	460,599	51,288,465
2058	186,751,760	636,966	11,953	110,186	4,457	1,120	37,911	465,093	51,852,230
2059	188,523,918	643,008	12,068	111,049	4,493	1,131	38,260	469,588	52,415,996
2060	190,295,951	649,050	12,184	111,911	4,530	1,141	38,609	474,083	52,979,762

[1] PM estimates are MOVES-based only (i.e., no re-suspended dust from roadways is included).
[2] 1990 and 1999 population data retrieved from https://www.tsl.texas.gov/ref/abouttx/census.html, 2000 through 2009 population data retrieved from https://www.census.gov/programs-surveys/popest/data/tables.2009.html, whereas 2010 through 2060 population projection retrieved from https://demographics.texas.gov/data/TPEPP/Projections/

1.3 Overview of Methodology

The EIs were calculated using the MOVES rates-per-activity estimation method for each of the 254 Texas counties, from 1990 and 1999 through 2060. This amounts to 16,002 county-level, MOVES3-based summer weekday EIs and 16,002 county-level, MOVES3-based annual EIs. This approach calculates on-network emissions and off-network emissions and formats results as needed for subsequent uses. The TTI rates-per-activity estimation method was performed using seven basic steps as described below:

- **Step 1** – Prepare Activity Inputs for MOVES Inventory Mode CDBs and for External EI Calculations: TTI conducted data source review and populated each of the MOVES CDB input tables using development procedures for local input data or input data alternatives to the MOVES defaults. The ATR and vehicle population-based activity data and local input data-based factor files such as hourly fractions, time periods and VMT mix files were prepared for estimation of traffic activity[6]. The details are covered in Section 2.

- **Step 2** - Estimate On-network Traffic Activity: For on-network vehicle activity (VMT), the county-level HPMS traffic data were processed to derive 24-hour (daily) VMT estimates summed from all HPMS links in all counties. Further

[6] Although only daily (24-hour aggregate) and annual level activity estimates were used in the emissions calculations for this project, TTI employed a standard time period-based activity estimation approach which retained greater temporal and spatial detail (Hourly HPMS Link Speeds, Hourly HPMS Link VMT, etc.) than needed. Per the trends EIs methodology, aggregations of these more detailed activity estimations were used in the EI calculations.

processing was used to convert AADT VMT with HPMS forecasting factors and scenario adjustment factors for summer weekday scenario and annual scenario developed from the latest available local automatic traffic recorder (ATR) traffic count data (2013 to 2020). The details of the methodology were covered in Section 3.

- **Step 3** – Estimate Off-network Traffic Activity: After the on-network vehicle activity was estimated, county-level off-network vehicle activity was calculated using outputs from the county-level scenario based VMT, vehicle population data, hotelling base scenario county-level VMT (2017 winter weekday), population/starts base scenario county-level VMT (2018 summer weekday) and MOVES default hotelling and starts inputs. The historic ratio and future growth factor of each scenario in each analysis year was estimated by scenario VMT with corresponding base scenario VMT. This off-network activity is ONI hours, SHP, starts, source hours extended idling (SHEI), and auxiliary power unit (APU) hours—where SHEI and APU hours are components of hotelling hours for combination long-haul trucks. The purpose of separate traffic activity estimation was processed to replicate the operating conditions with local parameters for each county based EI in each scenario. The details of the off-network activity estimation methodology were covered in Section 4.
- **Step 4** – Estimate Emission Factors: TTI prepared all 16,002 (254 Texas counties with 63 total analysis years) MOVES inventory mode CDBs as part of the deliverables in Task 3. In each analysis year, 254 Texas counties have been grouped into 36 to 44 county groups based on local fuel characteristics. In each county group, one representative county was selected to perform MOVES "Portion of Week" inventory mode runs. All counties in the same county group shared the same emission rates post-processed from the representative county MOVES run[7]. With the grouping method, a total of 2,749 representative CDBs for MOVES "Portion of Week" inventory mode runs were conducted using local input data (from the weekday/weekend EI activity data and various conversion factors) and some MOVES default input data. The MOVES "Portion of Week" inventory mode runs aggregate hourly results to output total emissions and activity over a 5-day work week portion and a typical 2-day weekend portion

[7] Grouping method helped to significantly reduce the total time for MOVES run from 64,008+ total hours (2+ hours per run per scenario) to 5,498 hours (~2 hours per run) while not losing resolution on emission rates with local fuel parameters.

for each month of the calendar year. The summer weekday rates were calculated by scaling the emissions and activity output for weekday June, July, and August to the entire month based on the number of weekdays in that month and summing the emission and activity to get the summer weekday scenario emission and activity, which in turn were used to calculate the summer weekday rates (summer weekday emissions divided by summer weekday activity). Annual average daily rates were computed using the emissions and activity from typical weekday and weekends from each of 12 months to the entire month based on the number of weekdays and weekends in that month and summing the emission and activity to get the annual emission and activity, which in turn were used to calculate the annual average daily rates (annual emissions divided by annual activity). Post-processing was performed using MOVES activity and emission output to produce the on-network and off-network emission rates in terms of mass per vehicle activity unit (i.e., mass/mile, mass/SHP, mass/start, mass/ONI hour, mass/SHEI, mass/APU hour). The details of the emission factor estimation methodology were covered in Section 5.

- **Step 5** – Develop Seasonal Emissions: The seasonal weekday emission rates calculated in Step 4 were multiplied by the on- and off-network seasonal weekday vehicle activity calculated in Step 1. This yielded emission estimates in units of mass calculated at a spatial scale of each MOVES road type and SUT/fuel type by county (on-network) or SUT/fuel type by county (off-network) for each 24-hour (daily).
- **Step 6** – Develop Annual Emissions: The annual average day emission rates calculated in Step 2 were multiplied by the on- and off-network annual vehicle activity calculated in Step 1 to calculate annual emissions. This yielded emission estimates in units of mass calculated at a spatial scale of each MOVES road type SUT/fuel type by county (on-network) or SUT/fuel type by county (off-network) by analysis year.
- **Step 7** – Post-Process EI Outputs: Outputs for each county were post-processed into required formats and electronic deliverables for reporting purposes and for downstream air quality planning.

The following five subsections (Emissions Inventory Parameters; Source Use Types, Activity, and Pollutant Processes; Pollutants Modeled; Emission Rate (MOVES) Input

Data; Traffic Activity Input Data) provide detailed lists of the scope of criteria used for the preparation of the emissions inventory products.

1.3.1 Emissions Inventory Parameters

Emissions inventories were developed to model the following emissions parameters:

- Analysis years – 1990, 1999 to 2060 (a total of 63 analysis years).
- Summer work weekday (Monday through Friday) emissions statewide for all 254 counties. Adjust the average annual weekday to the average for summer months.
- Annual emissions (calendar year totals) statewide for all 254 counties.

The level of detail in the final EI estimates is period (average summer weekday and annual) aggregate emissions by county, fuel type, and SUT.

1.3.2 Source Use Types, Activity, and Pollutant Processes

- SUTs and fuel types modeled—the various combinations of these are referred to as vehicle types as described in Table 9.

Table 9. MOVES SUT/Fuel Types (Vehicle Types).

SUT ID	SUT Description	SUT Abbreviation[1]	Fuel Types
11	Motorcycle	MC	Gasoline
21	Passenger Car	PC	Gasoline, Diesel
31	Passenger Truck	PT	Gasoline, Diesel
32	Light Commercial Truck	LCT	Gasoline, Diesel
41	Other Buses	Obus	Gasoline, Diesel
42	Transit Bus	Tbus	Gasoline, Diesel
43	School Bus	Sbus	Gasoline, Diesel
51	Refuse Truck	RT	Gasoline, Diesel
52	Single Unit Short-Haul Truck	SUShT	Gasoline, Diesel
53	Single Unit Long-Haul Truck	SULhT	Gasoline, Diesel
54	Motor Home	MH	Gasoline, Diesel
61	Combination Short-Haul Truck	CShT	Gasoline, Diesel
62	Combination Long-Haul Truck	CLhT	Diesel

[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 gasoline-powered motorcycles, diesel-powered refuse trucks, and gasoline-powered school buses).

- Traffic activity modeled: VMT, vehicle starts, hoteling hours (classified by auxiliary power unit [APU], engine on, engine off), source hours parked, off-network idling.
- Vehicle-based emission processes modeled: running exhaust; crankcase running exhaust; start exhaust; crankcase start exhaust; extended idle exhaust; crankcase extended idle exhaust; auxiliary power exhaust; evaporative permeation; evaporative fuel vapor venting; evaporative liquid leaks; brakewear; and tirewear.

1.3.3 Pollutants Modeled

- CAPs and CAP precursors for the daily and the annual emissions inventories—the CAP precursors include VOC, CO, NO_X, SO_2, NH_3, CO_2, $PM_{2.5}$, and PM_{10}.
- HAPs for annual emissions inventories— The HAPs to be included are: benzene, ethanol, naphthalene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and diesel PM plus diesel exhaust organic gases.

1.3.4 Emission Rate (MOVES) Input Data

- *Emission rates:* EPA's latest mobile source emission rate model—MOVES3.0.3 (herein abbreviated to MOVES). The latest version of the model upon commencement of this work was released in March 2021. MOVES installation suites were downloaded from the following link: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves [8]
- *Local meteorologic data*: 2019 climate inputs (temperature, humidity, barometric pressure) provided by the TCEQ.
- *Local fuel formulation input data:*
    - Consistent with the TCEQ 2020 Summer Fuel Field Study conducted by Eastern Research Group (ERG) under contract to TCEQ, available at https://www.tceq.texas.gov/airquality/airmod/project/pj_report_mob.html.

[8] Note that inventory mode runs in this project used MOVES3.0.3 released in January 2022.

- MOVES individual fuel parameter inputs were used to model the Low RVP gasoline control strategy for applicable counties, consistent with Sections 114.301-114.309 of TCEQ rules.[9]
- Modeled reformulated gasoline for the HGB area and the four DFW counties—Collin, Dallas, Denton, and Tarrant.
- Modeled the effects of the oxygenated fuel program for El Paso.
- Modeled Texas Low Emission Diesel (TxLED) program effects by post-processing diesel NO_X emission factors consistent with 30 Texas Administrative Code (TAC) Sections 114.312 – 114.319.

- *Inspection and maintenance (I/M) program information*: Modeled I/M programs currently administered in the Austin-Round Rock, DFW, HGB, and El Paso areas.
- *Federal motor vehicle control programs (FMVCP)*: Modeled the effects of all FMVCP in Texas, as incorporated by default in MOVES.

1.3.5 Traffic Activity Input Data

- HPMS-based VMT for all 254 counties in Texas.
- TxDOT traffic count data (2013 to 2020) was used to derive seasonal, day type, and hour-of-day traffic patterns.
- HPMS data for deriving HPMS adjustment factors and historical year county VMT control totals.
- Base hoteling hours data sourced from TTI's 2017 hotelling study.[10]
- MOVES default hoteling operating mode distributions.
- MOVES defaults for the number of vehicle starts per local vehicle type population estimates.
- Vehicle population data: End of year 2018 vehicle registrations and age class data classified by source use and fuel type provided by the Texas Department

[9] Code of Federal Regulations, Title 40 – Protection of the Environment, Part 80 – Regulation of Fuels and Fuel Additives, Section 27 – Controls and Prohibitions on Gasoline Volatility.

[10] Heavy-Duty Vehicle Idle Activity Study Final Report, prepared by TTI for TCEQ, July 2019.

of Motor Vehicles (TxDMV) with VMT-based scaling factors for estimating all analysis years.

- For the local fleet mix:
    - TxDOT traffic classification data.
    - TxDMV vehicle registration data.
    - MOVES default data as needed.

1.4 DELIVERABLES

The deliverables for this project and their delivery dates are listed in Table 10. TTI has submitted all deliverables for Tasks 1 through 4 by their designated delivery date.

It must be noted that Deliverables 3.3 and 3.4, which are the draft and final rate mode MOVES CDB files, were not produced under TTI's current method of developing the trends EIs. The current method processes the MOVES activity and emissions output by the month and day type (portion of week) twice: once to produce the summer weekday EIs, and then once more to produce the annual EIs. Thus, only one set of MOVES inventory mode CDB, MOVES run specification (MRS), and MOVES run was required to produce EIs for both the summer weekday and annual periods, and therefore, no rates mode CDBs were needed.

The finalized MOVES3 inventory mode CDB and its input database, which were part of deliverable 3.6 and were previously submitted to TCEQ project managers on December 11th, 2022, are included with this report electronically, as Appendix A (Appendix A.1 for the annual period and Appendix A.2 for the summer weekday period) and B, respectively.

Table 10. Summary of Deliverables and Deliverable Dates

Deliverable	Deliverable Date
GAD (Task 1) **Deliverable 1.1:** TCEQ approved GAD **Deliverable 1.2:** TCEQ approved QAPP	**(1.1):** Within fourteen (14) calendar days after this PGA is issued by TCEQ **(1.2):** Within fourteen (14) calendar days after this PGA is issued by TCEQ
Progress Reports (Task 2) **Deliverable 2.1:** Monthly Progress Reports	**(2.1):** Monthly
Development and Production of Trend Emissions Inventories (Task 3) **Deliverable 3.1:** Draft Task 3 electronic data including, but not limited to, county MOVES inputs, script files used to load county MOVES inputs into MOVES CDB files, and MRS files **Deliverable 3.2:** Draft Task 3 electronic data including, but not limited to, county MOVES inputs, script files used to load county MOVES inputs into MOVES CDB files, and MRS files **Deliverable 3.3:** Draft rate mode MOVES CDB files **Deliverable 3.4:** Final rate mode MOVES CDB files **Deliverable 3.5:** Draft inventory mode MOVES CDB files **Deliverable 3.6:** Final inventory mode MOVES CDB files	**(3.1):** April 22, 2022 **(3.2):** May 6, 2022 **(3.3):** April 22, 2022 **(3.4):** May 6, 2022 **(3.5):** October 21, 2022 **(3.6):** November 4, 2022
Inventory Summary Files and CERS XML Files (Task 4) **Deliverable 4.1:** Draft inventory summary files in tab-delimited format based upon the MOVES source use types **Deliverable 4.2:** Final inventory summary files in tab-delimited format based upon the MOVES source use types **Deliverable 4.3:** Draft inventory summary files in tab-delimited format based on upon EPA's SCCs **Deliverable 4.4:** Final inventory summary files in tab-delimited format based on upon EPA's SCCs **Deliverable 4.5:** Draft inventories in EPA's CERS XML format for upload into TCEQ's TexAER system **Deliverable 4.6:** Final inventories in EPA's CERS XML format for upload into TCEQ's TexAER system	**(4.1):** August 16, 2022 **(4.2):** August 24, 2022 **(4.3):** August 16, 2022 **(4.4):** August 24, 2022 **(4.5):** August 16, 2022 **(4.6):** August 24, 2022
Draft and Final Reports (Task 5) **Deliverable 5.1:** Draft Report **Deliverable 5.2:** Final Report **Deliverable 5.3:** Final supporting electronic document files (project electronic data), updated upon TCEQ comments, that meet the requirements of all tasks and the Electronic Deliverables Section of this PGA.	**(5.1):** January 6, 2023 **(5.2):** January 20, 2023 **(5.3):** January 6, 2023

Task 5 includes the draft and final report for this project, which compiles and summarizes the deliverables from previous tasks.

TTI included the following elements in the Draft Report:

- A description of all pertinent activities related to the completion of Task 3 and Task 4.
- A description of all methodologies used to develop model inputs, activity parameters, and emissions estimates.
- A description of the model inputs shall be documented.
- A description of the electronic files submitted in conjunction with the Final Report.
- Summary tables of inventory results by SUT for each county.
- Summary tables of speed and VMT by SUT for each county.
- A list of references.
- A description of the factors influencing the trends.
- Summary trend inventory information by county and year, presented in graphical as well as tabular formats.
- A summary of the on-road activity parameters, including vehicle population, human population, VMT, source hours idling, and starts.
- Key parameters associated with on-road mobile source control programs, including program description, implementation date, geographic coverage, end date (if applicable), and vehicle type coverage.

The Final Report includes the following components:

- An executive summary or abstract.
- A brief introduction that discusses the background and objectives, including relationships to other studies if applicable.
- A discussion of the pertinent accomplishments, shortfalls, and limitations of the activities completed under each GAD task.
- Recommendations, if any, for what should be considered next as a new study.

1.4.1 Electronic Delivery

The Draft and Final Reports were prepared and will be delivered in both Microsoft® Word and PDF electronic copy formats. TTI made sure all electronic deliverables met State of Texas Accessibility requirements in 1 TAC Part 10, Chapter 213 and Section 508 of the Americans with Disabilities and Rehabilitation Act.

1.5 Report Organization

The discussion was organized into the following sections: Estimation of On-network Vehicle Activity (Section 2); Estimation of Off-network Vehicle Activity (Section 3); Inputs Development for MOVES CDBs (Section 4); Estimation of Emission Factors (Section 5); Emissions Calculations (Section 6); Quality Assurance (Section 7); and, lastly, Findings and Recommendations (Section 8); followed by References (Section 9).

2 ESTIMATION OF ON-NETWORK VEHICLE ACTIVITY

This section covers the components that the time period based VMT estimation approach TTI took to estimate the on-network vehicle activity (VMT) required for all 254 counties in Texas, by analysis year, MOVES roadway type, and analysis scenario. These activity estimates were produced for input to the external summer weekday and annual emissions calculations and further processed and formatted for input to the MOVES CDBs developed for all counties and years.

2.1 VMT AND VMT FACTORS DATA SOURCES

There were three major traffic data sources used in this project for developing the VMT estimates and VMT adjustment and allocation factors for the emissions inventory. The first two, the ATR counts and HPMS VMT estimates, are collected and developed regularly by TxDOT as part of the larger HPMS data collection program. In addition to these traffic data, U.S. Census and Texas State Data Center (TSDC) county human population statistics and projections were also used in developing VMT forecasts, if applicable.

HPMS VMT estimates were developed based on ATR data collected according to a statistical sampling procedure specified by the Federal Highway Administration (FHWA) designed to estimate VMT. TxDOT compiles and reports Texas HPMS data in its annual Roadway Inventory Functional Classification Record (RIFCREC) reports. A wide range of traffic data is collected under the HPMS program; however, the focus for this application was specifically the VMT, centerline miles, and lane miles estimates. The HPMS roadway data were categorized by seven roadway functional classifications and four area types.

Seasonal and day-type factors derived from local ATR data were used to translate the traffic activity represented by the HPMS based VMT to those defined for each emissions scenario. These seasonal and day-type factors were estimated using ATR data collected from 2013 through 2020. TxDOT collects ATR vehicle counts at selected locations continuously throughout Texas. These counts are available by season, month, and day type, for seasonal scenarios as well as on an AADT basis for annual estimation. Since they are continuous, they are well suited for making seasonal, day-of-week, and time-of-day comparisons (i.e., adjustment factors), even though there may be relatively few ATR data collection locations in any area.

2.2 TTI Speed Model

The estimation of congested speeds using the TTI Speed Model is a two-step process. The first step is the volume to capacity (V/C) ratio calculation. The second step is the application of the congested speed model to estimate the congested speed.

V/C ratios are generated for each combination of time period (hour), roadway functional classification, area type, and direction using the hourly lane capacities and VMT. The calculations for this procedure are:

- Volume: hourly VMT by direction (discussed in the previous section) is divided by centerline miles, yielding volume for each hour. This procedure was performed for each HPMS-based link (i.e., roadway functional classification and area type combination);
- Capacity: lane miles are divided by centerline miles to produce lanes. Lanes are multiplied by the hourly lane capacities (i.e., adjusted saturation flows) generated by the process described previously, producing hourly capacities. This procedure was performed for each HPMS-based link. (Capacity is the same for each hour and each direction.); and
- V/C ratios: the speed model uses the hourly volumes and capacities to produce hourly, directional V/C ratios for each roadway functional classification and area type combination. These V/C ratios are used to calculate hourly, directional congestion-related delay, and congested speeds (as described in the next section) by functional classification and area type combination.

The congested speed model calculates delay on the link and then applies this delay to the link free-flow speed to calculate the link operational congested speed estimate. The volume/delay equation is:

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

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 v/c ratio.

There are two sets of delay model parameters A, B, and M, as shown in Table 11 — one set for high-capacity facilities and one set for low-capacity facilities. The HPMS high-capacity facilities are the Interstate and Freeway classifications.

Table 11. Volume/Delay Equation Parameters.

Facility Category	A	B	M
High-Capacity Facilities (> 3,400 volume per hour [vph] one way, e.g., Interstates and Freeways)	0.015	3.5	1.0
Low-Capacity Facilities (≤ 3,400 vph, e.g., Arterials, Collectors and Locals)	0.050	3.0	2.0

Given the estimated directional delay (in minutes/mile) and the estimated free-flow speed, the directional congested speed is calculated as follows:

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

For each daily inventory, this model was applied to each link, based on functional class and area type, for each hour and each direction.

2.3 Road Type Based VMT Mix

Road type based VMT mix represents the fraction of on-road fleet VMT attributable to each SUT by fuel type and was needed for the daily and annual activity estimations. These VMT mixes were used to subdivide the total VMT estimates into VMT by vehicle type. The 24-hour VMT estimates by vehicle type were combined with the appropriate emission factors in the emissions calculations.

VMT mixes were calculated by TxDOT districts and applied at the scale of:

- Every Texas county.
- Analysis years 1990 and 1999 through 2060.
- Each MOVES roadway type.
- Scenarios (summer weekday and annual average daily).
- Four time periods per day (morning peak, midday, afternoon peak, and overnight).

The core methodology of using TxDOT classification count averages over a district, road type, and TOD stays the same, with changes to mapping data used for converting TxDOT classification categories to the MOVES SUTs then to MOVES SUT and fuel type categories. Figure 1 shows the overview of the SUT VMT mix development. After obtaining the SUT VMT mix, the MOVES default fuel distribution is used to split the SUT distribution further into SUT and fuel type distribution.

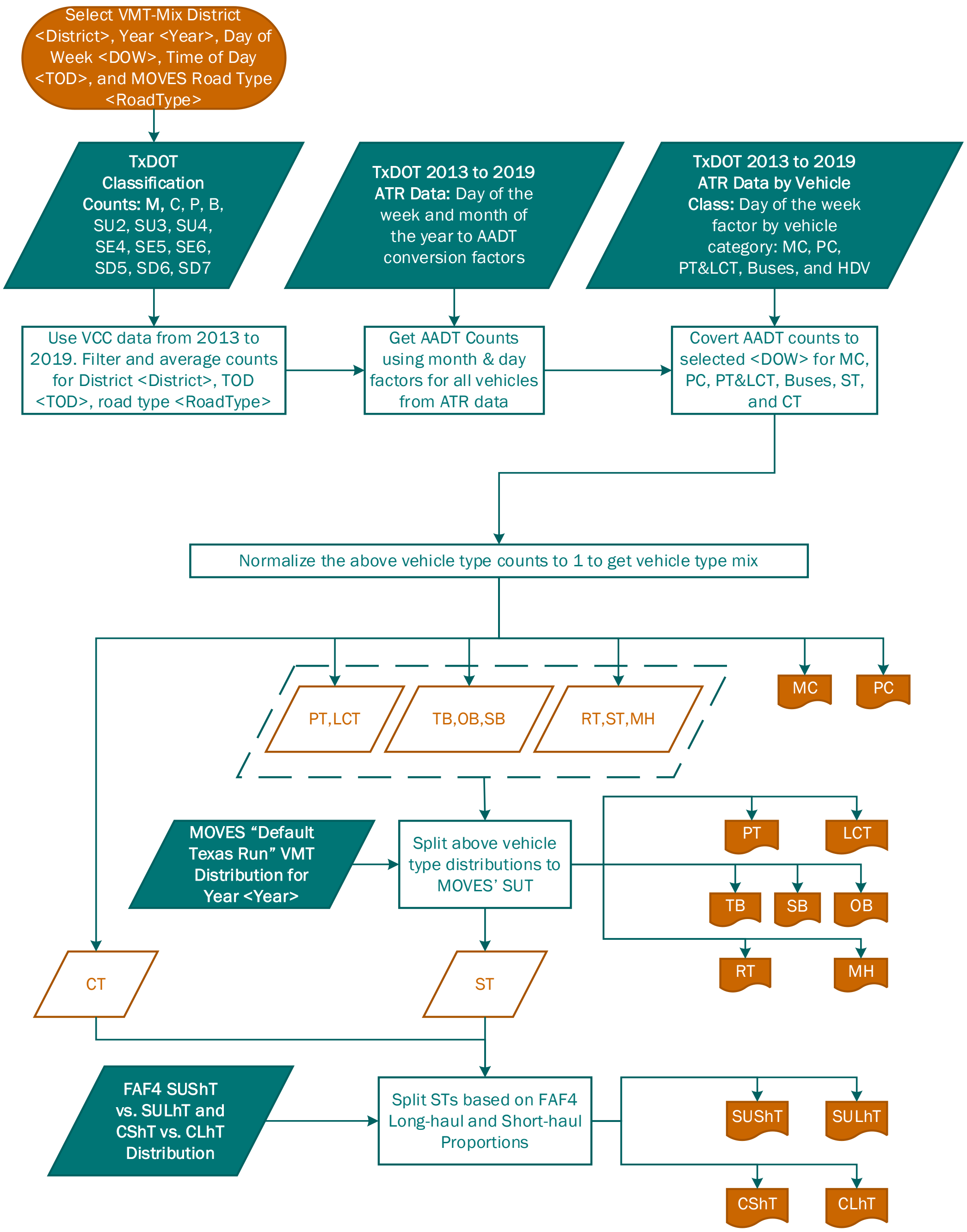

Figure 1. Overview of SUT (without Fuel-Type) VMT Mix Development.

The following are the keys steps used for obtaining the VMT mix:

1. 2013 to 2019, "TxDOT VCC Data received in March 2022" was used to obtain the counts for HPMS vehicle categories M, C, P, B, SU2, SU3, SU4, SE4, SE5, SE6, SD5, SD6, SD7. These categories are combined into the "Modified MOVES HPMS Vehicle Category" listed in Table 12 below, which maps the TxDOT VCC categories to MOVES HPMS and SUT categories.

Table 12. TxDOT VCC Category Mapping to HPMS Vehicle, Modified HPMS Vehicle, and MOVES3 SUT Categories.

TxDOT VCC Category	MOVES HPMS Vehicle Category	Modified MOVES HPMS Vehicle Category	MOVES SUT Category
M	Motorcycles	Motorcycles	MC
C	Light duty vehicles	Light duty vehicles: passenger cars	PC
P	Light duty vehicles	Light duty vehicles: other than passenger cars	PT + LCT
B	Buses (B)	Buses	TB + SB + OB
SU2 + SU3 + SU4	Single unit trucks (ST)	Single unit trucks	RT + SUShT + SULhT + MH
SE4 + SE5 + SE6 + SD5 + SD6 + SE7	Combination trucks (CT)	Combination trucks	CShT + CLhT

[1]TxDOT VCC are aggregated to MOVES HPMS vehicle category counts, except "Light-duty vehicles."
[2]TxDOT VCC category "C" maps directly to PC SUT, so, it can be used directly.
[3]TxDOT VCC category "P" maps to be PT and LCT and thus can be aggregated together.
[4]The "Modified MOVES HPMS Vehicle Category" column shows the vehicle categories that can be used to aggregate TxDOT VCC data at finer resolution than the MOVES HPMS vehicle categories.
[5]"Modified MOVES HPMS Vehicle Category" count or distribution can then be split into MOVES SUT distribution based on default scale inventory mode run outputs or other datasets.

2. Since the counts can be conducted during different months of the year and days of the week, this study used (month + DOW) factors to convert the counts to annual counts.

3. This study then used data from the permanent counter with vehicle classification information to get the DOW factors by vehicle category. These factors were applied to annual counts to get Weekday, Friday, Saturday, and Sunday counts.

4. Texas state-level MOVES3 runs between 2010 and 2060 at a 5-year interval were used to split "Modified MOVES HPMS Vehicle Category" counts to get VMT mix by MOVES SUTs.

5. This study used FAF4 data based on an ERG report to distinguish long-haul vs. short-haul for ST and CT for Texas (John Koupal et al., 2014).

6. sourceTypeAgeDistribution and sampleVehiclePopulation from MOVES' default database were used to get fuel fractions for gasoline and diesel and applied to the SUT distribution obtained from previous steps.

7. The hourly counts were then filtered and aggregated to different TODs and normalized to one to get TOD VMT mix.

Using the same data sets and a similar procedure, aggregate (i.e., all road-type categories), and TxDOT district-level weekday vehicle-type VMT mixes (used in the vehicle population estimation process) were also produced. To ensure general applicability and consistency across all study areas, all VMT mixes were developed for 1990 and in five-year increments beginning with the year 2000 and applied to the analysis years based on Table 13.

Table 13. VMT Mix Year/Analysis Year Correlations.

VMT Mix Year	Analysis Years
1990	1990
2000	1999 through 2002
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 through 2052
2055	2053 through 2057
2060	2058 through 2060

2.4 Hourly Travel Factors

Hourly travel factors were used to distribute 24-hour link VMT estimates to each hour of the day. These hourly travel factors were developed using multi-year (2013 through 2020) aggregated ATR station data for each TxDOT district. For the summer weekday analyses, the total VMT and volumes (by the 24-hour period for statewide HPMS-based) were reallocated to replicate summer weekday traffic profiles. For the annual analyses, the total VMT and volumes (by the 24-hour period for statewide HPMS-based) were reallocated to replicate annual average daily traffic profiles. To maintain VMT proportions within each of the four assignment time periods, the hourly fractions were normalized within each time period to produce the time period hourly travel factors. Each factor (i.e., 24 or one for each hour of the day) was then multiplied by the link volume (in addition to the other VMT adjustment factors). These adjusted link volumes were then multiplied by their respective link lengths to estimate the link-level VMT for seasonal weekdays. Hourly travel factors are shown in Appendix D.

2.5 Estimation of Summer Weekday VMT

The 24-hour aggregate summer weekday emissions inventory calculations required 24-hour aggregate summer weekday VMT estimates by vehicle category and MOVES road type for each county and analysis year. The following sections described the details of the estimation of 24-hour aggregate summer weekday VMT for each county in each analysis year.

2.5.1 Summer Weekday VMT Control Totals

The summer weekday control totals of all analysis years were estimated. For historical analysis years (years equal to or before 2020), the historical HPMS AADT VMT was used for the county AADT VMT estimates. For future analysis years, TTI used an HPMS and population-based method to forecast aggregate county AADT VMT estimates for each future analysis year. With this method, the AADT VMT forecast is produced as the combination of two intermediate forecasts —one based on population projections, and the other based on the historical, actual HPMS AADT VMT.

The VMT per-capita-based forecasts were developed using VMT-to-population ratios applied to official TSDC population forecasts for each county and future analysis years. The growth-based VMT forecasts were developed using traditional regression analyses on historical HPMS AADT VMT data (i.e., from 1990 through 2020). Population-based forecasts (i.e., VMT per capita) tend to underestimate future VMT, especially in small counties adjacent to large urban areas.

Conversely, historical-based (i.e., growth trend) forecasts tend to overestimate future VMT, especially in areas where there has been recent atypical rapid growth. These two forecast streams, however, form a range of credible results. The HPMS and population-based VMT forecasting method combines the population-based and historical VMT-based forecast streams with equal weight, and then calibrates the combined forecast result to the latest HPMS historical VMT (2020) data using a step-function adjustment.

Since the VMT data were in AADT form (i.e., Monday through Sunday, January through December), the summer weekday VMT factors were needed to convert from AADT to traffic characteristic of a summer weekday. Summer weekday was defined as June through August, Monday through Friday. Multiple years of TxDOT District ATR vehicle count data (i.e., 2013 through 2020) were aggregated to develop the summer weekday VMT adjustment factors for each TxDOT district (each county within a TxDOT district uses the same summer weekday VMT adjustment factors). The factors were calculated as the ratio of average period "day type" volumes to the AADT volumes. The same district-level seasonal day-type factors were used for all analysis years.

County-level analysis summer weekday VMT control totals were used to produce the county-level summer weekday VMT estimates by MOVES road type and vehicle category.

2.5.2 24-Hour Summer Weekday VMT by MOVES Road Type and Vehicle Category

The county summer weekday VMT control totals were allocated to MOVES road type and to each VMT mix vehicle category for input to the summer weekday emissions calculations. In the process, the hourly VMT was saved for future uses as well as some other aggregations.

County historical HPMS road type and area type VMT were aggregated to MOVES road type and MOVES road type allocation factors were calculated. These MOVES road type allocation factors were used to allocate the control total VMT to the four main MOVES road types. District ATR summer weekday hourly factors calculated in Section 3.4 were used to further allocate VMT by hour of day. The summer weekday time-of-day VMT mixes calculated in Section 3.3 were applied to the fleet VMT within each hour to allocate hourly VMT to vehicle category. The latest available (2020) HPMS road type proportions were used for future years. The MOVES road type and vehicle category hourly VMT were aggregated to the 24-hour summer weekday level for input to the emissions calculations.

The 24-hour summer weekday county VMT summaries (by road type and vehicle type) for each inventory scenario were produced and were included with the detailed inventory data provided in Appendix H.

2.6 Estimation of Annual VMT

The aggregate annual emissions inventory calculations required annual aggregate VMT estimates by vehicle category and MOVES road type for each county and analysis year. The annual VMT estimates were calculated from annual average daily VMT estimates multiplied by 365 days per analysis year. The following sections describe the details on estimation of annual VMT for each county in each analysis year.

2.6.1 Annual Average Daily VMT Control Totals

The annual average daily control totals for all analysis years were estimated using a method like that used for development of the summer weekday daily control totals (as described in Section 2.5.1). For historical analysis years (years equal or before 2020), the historical HPMS AADT VMT was used for the county AADT VMT estimates. For future analysis years, TTI used the HPMS and population-based method to forecast aggregate county AADT VMT estimates for each future analysis year. With this method, the AADT VMT forecasts were produced as the combination of two intermediate forecasts —one based on population projections, and the other based on the historical, actual HPMS AADT VMT.

The VMT per-capita-based forecasts were developed using VMT-to-population ratios applied to official TSDC population forecasts. The growth-based VMT forecasts were developed using traditional regression analyses on historical HPMS AADT VMT data (i.e., from 1990 through 2020). The HPMS and population-based VMT forecasting method combines the population-based and historical VMT-based forecast streams with equal weight, and then calibrates the combined forecast result to the latest HPMS historical VMT (2020) data using a step-function adjustment.

Since the VMT data were in AADT form (i.e., Monday through Sunday, January through December), no other seasonal adjustment factors were required for annual scenario.

County-level AADT VMT control totals were used to produce the county-level AADT VMT estimates by MOVES road type and vehicle category.

2.6.2 Annual VMT by MOVES Road Type and Vehicle Category

The county AADT VMT control totals were allocated to MOVES road type and to each VMT mix vehicle category for input to the annual emissions calculations. In the process, the hourly VMT were saved for future uses as well as some other aggregations.

County historical HPMS road type and area type VMT were aggregated to MOVES road type and MOVES road type allocation factors were calculated. These MOVES road type allocation factors were used to allocate the control total VMT to the four main MOVES road types. District ATR annual average daily hourly factors calculated in Section 3.4 were used to further allocate VMT by hour of day. The appropriate annual average time-of-day VMT mixes calculated in Section 3.3 were applied to the fleet VMT within each hour to allocate hourly VMT to vehicle category. The latest available (2020) HPMS road type proportions were used for future years. On the other hand, the MOVES road type and vehicle category aggregated 24-hour AADT VMT were then multiplied by 365 to get the annual level for input to the annual emissions calculations.

The annual county VMT summaries (by road type and vehicle type) for each inventory scenario were produced and were included with the detailed inventory data provided in Appendix J.

2.7 Estimation of On-network Activity Inputs for MOVES CDB Tables

The on-network activity tables included those needed for the county's annual VMT and several VMT and source hours operating (SHO) allocation factors. The CDB input tables derived from the estimation of on-network activity are:

- hpmsvtypeyear (county, analysis year, annual VMT by HPMS vehicle class)
- monthvmtfraction (fraction of annual VMT for each month by source type)
- dayvmtfraction (fraction of monthly VMT for each day type by source type and road type)
- hourvmtfraction (fraction of day type VMT for each hour of the day by source type and road type)

The hpmsvtypeyear table was created based on the MOVES VMT allocation procedure from the AADT VMT by HPMS vehicle type:

$$AVMT_{HPMSVtype} = AADTVMT_{HPMSVtype} * 365$$

Where:

$AADTVMT_{HPMSVtype}$ = annual average daily VMT by HPMS vehicle type;

$AVMT_{HPMSVtype}$ = annual VMT by HPMS vehicle type;

The monthvmtfraction table was created using the similar calculation of creating seasonal adjustment factors. Multiple years of TxDOT district ATR vehicle count data (i.e., 2013 through 2020) were aggregated to develop the monthly VMT adjustment factors for each TxDOT district (each county within a TxDOT district uses the same monthly VMT adjustment factors). The factors were calculated as the ratio of average "monthly" counts to the annual counts. The same district-level monthly factors were used for all analysis years.

The dayvmtfraction table was created using multiple years of TxDOT district ATR vehicle count data (i.e., 2013 through 2020) which were aggregated to develop the "day-type" VMT adjustment factors for each TxDOT district (each county within a TxDOT district uses the same monthly VMT adjustment factors). The factors were calculated as the ratio of average MOVES "day-type" counts to the typical weekly counts in each month. The same district-level "day-type" factors were used for all analysis years.

The hourvmtfraction table was created using multi-year (2013 through 2020) aggregated ATR station data for each TxDOT district. The factors were calculated as the ratios of average "day-type" hourly counts to the typical "day-type" annual average daily (24-hour) counts. The same district-level "hourly" factors were used for all analysis years.

3 ESTIMATION OF OFF-NETWORK VEHICLE ACTIVITY

To estimate the off-network (or parked vehicle) emissions using the mass per activity emissions rates (i.e., mass per SHP, mass per start, and mass per SHEI), county, analysis year scenario estimates of the SHP, starts, SHEI, ONI and APU hours are required by vehicle category (SHEI and APU hours are for diesel combination long-haul trucks only). The following sections detail estimation of off-network ONI hours, SHP, starts, and long-haul combination truck hotelling hours (split into various fractions of activity, such as SHEI and diesel APU hours) at a spatial scale of a county and for each MOVES SUT and fuel type combination in both summer weekday and annual scenarios in each analysis year. These activity estimates were produced for input to the external summer weekday and annual emissions calculations and further processed and formatted for input to the MOVES CDBs developed for all counties and years.

3.1 Off-network Activity Data Sources

The major data used in this project for developing the off-network vehicle activities are listed as follows:

- Vehicle registration data and corresponding VMT control totals: end of year 2018 county-specific vehicle registration data provided by TxDMV and 2018 summer weekday county-level VMT control totals.
- No-road type VMT Mix: TxDOT district-level VMT mix data without MOVES road type specifications.
- HPMS based Scenario VMT control totals calculated from Section 2.
- Hotelling base year vehicle hotelling hours and VMT control totals: 2017 winter weekday statewide county-level hotelling hours and county-level VMT control totals.
- MOVES default road idle fraction table.
- Scenario adjusted total idle fraction table from MOVES default database. (3-month average for summer weekday scenario and 12-month average for annual scenario)
- MOVES default hotelling activity distribution table.
- MOVES default relative accumulative rates (relMAR) table.

- Components of the MOVES starts per vehicle calculation algorithm including CDB/MOVES default based age distribution, avft, starts hour fractions, starts month adjustment, starts per vehicle tables.

3.2 No-Road Type VMT Mix

"No-Road type" based VMT mix represents the fraction of off-network fleet VMT attributable to each SUT by fuel type and was needed for the daily and annual off-network activity estimations. These VMT mixes were used to subdivide the total vehicle population estimates into population by MOVES vehicle type.

"No-Road type" VMT mixes by TxDOT district were calculated and applied at the scale of:

- Every Texas county.
- Analysis years 1990 and 1999 through 2060.
- Scenarios (summer weekday and annual average daily).
- Four time periods per day (AM peak, midday, PM peak, and overnight).

The core methodology of using TxDOT classification count averages over a district, sum of all road types, and TOD stays the same, with changes to mapping data used for converting TxDOT classification categories to the MOVES SUTs to MOVES SUT and fuel type categories. The methodology of developing "No-Road type" based VMT mix is similar to the methodology of developing road-type based VMT mix described in Section 2.3, except for using sum of all MOVES road types instead of each MOVES road type. Consistent with the estimation of the on-network VMT mix, after obtaining the SUT "no-road type" VMT mix, the MOVES default fuel distribution is used to split the SUT distribution further into the SUT and fuel type distribution. The TxDOT mapping from the HPMS vehicle types and to the VMT mix years for the "No-Road type" VMT mixes is the same as on-network VMT mix shown in Table 12 and Table 13.

3.3 Estimation of Vehicle Population

Vehicle population data were used to estimate SHP and vehicle starts off-network activity. The vehicle population estimates were derived from end of year 2018, county-specific vehicle registration data provided by the TxDMV, TxDOT district-level "No-road type" VMT mix data, and HPMS reported county-level VMT totals.

A single set of vehicle population data inputs were used for the analysis periods (i.e., the model assumes that vehicle populations remain constant across seasons and days in each year).

The end of year 2018 TxDMV vehicle registration data was provided in the form of total vehicles registered by county, aggregated by the vehicle categories shown in the first column of Table 14. These TxDMV vehicle categories were disaggregated to MOVES SUT and fuel type aggregations shown in the corresponding rows of the second column of Table 14. As previously mentioned, in MOVES emissions analyses, TTI uses the term *vehicle type* as synonymous with MOVES SUT and fuel type combination.

Table 14. TxDMV Vehicle Registration Aggregations and Associated Vehicle Types for Estimating Vehicle Populations.

Vehicle Registration[1] Aggregation	MOVES SUT and Fuel Type (Vehicle Type)
Motorcycles	MC_Gas
Passenger Cars	PC_Gas; PC_Diesel
Trucks <= 8.5 K gross vehicle weight rating (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 Obus_Gas; Obus_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.

The following steps were used to disaggregate the TxDMV vehicle registration data into vehicle population data by vehicle type.

- **Step 1** – VMT mix data was used to calculate the proportional representation of each MOVES vehicle type within each TxDMV aggregation class (first column of Table 14).
- **Step 2** – The proportional fractions calculated in Step 1 were multiplied by the total number of vehicles reported in each TxDMV vehicle registration

category to obtain the estimated number of vehicles (populations) for each modeled MOVES vehicle type.

- **Step 3** – The long-haul truck vehicle type populations (see last row of Table 14) were estimated as an extension of their estimated short-haul vehicle type population counterparts by multiplying a long-haul-to-short-haul ratio derived from the weekday vehicle type VMT mix, by the associated short-haul truck vehicle type populations, from Step 2.

The VMT mix data used in these calculations was the TxDOT district-level, 24-hour weekday VMT mix are included in Appendix E. The methods above yielded end of year 2018 vehicle population data for each of the vehicle types modeled in the EIs.

Analysis year vehicle type populations were then calculated by applying a vehicle types population growth factor (VPGF). The VPGF was calculated using summer weekday county-level HPMS reported total VMT for the registration data year (2018) and the analysis year VMT.

VPGF = Analysis Year SWKD VMT / Registration Year SWKD VMT

3.4 ONI Hours

Off-network idling or ONI is idling activity that occurs while a vehicle is idling in a parking lot, drive-through, driveway, while waiting to pick up passengers, or loading/unloading cargo. ONI applies to all MOVES source types.

TTI estimates ONI activity for each hour of the day using the following formula:

$$ONI\ Hours = (SHO_{network} * TIF - SHI_{network}) / (1 - TIF).$$

Where:

$SHO_{network}$ = the SHO on each link. This is calculated by dividing the VMT associated with each link by the link's congested speed.

$SHI_{network}$ = the total source hours idling (SHI) that occurs on the network (idling that occurs as a component of drive cycles) and is calculated by multiplying $SHO_{network}$ by a road idle fraction (RIF). RIF is the proportion of idling (in units of time) that occurs within a drive-cycle at a specified operational speed. Default values for RIF were used as defined in the MOVES data table *roadidlefraction*.

TIF = the total idle fraction, i.e., the ratio of total source hours idling and total source hours operating. Default values for TIF were used as defined in the MOVES database table *totalidlefraction* (three-month seasonal averages for summer weekday scenario and 12-month averages for annual scenario).

3.5 SHP

County-level vehicle type SHP was calculated for each hour of the day and each vehicle type as the difference between the local vehicle population (total available source hours) minus SHO. If the SHO is greater than the source hours, the SHP is set to zero. This calculation is performed for each vehicle type.

Adjusted SHP was then calculated by subtracting ONI hours from the previously calculated SHP. Appendix F provides county-level SHP and adjusted SHP by 24-hour and vehicle type for each analysis year and activity scenario. The 24-hour summaries of summer weekday scenario and annual summaries were provided electronically; see Appendix F for electronic data descriptions.

3.6 Vehicle Starts

TTI estimated vehicle starts using county-level vehicle type populations and data from MOVES representing the average number of vehicle starts per vehicle type per hour.

The starts per vehicle were calculated using the MOVES algorithm with data on the age distribution and fuel fractions of the local fleet[11]. TTI used local age distributions and fuelfractions inputs to MOVES combined with MOVES default parameters (startsageadjustment, startsmonthadjust [three-month seasonal average for summer weekday scenario and 12-month average for annual scenario], and startspervehicle) to produce 24-hour starts per vehicle output representative of each seasonal period. The MOVES output from inventory mode MOVES runs provided the scenario-specific starts per vehicle defined by the study scope.

[11] Previously with MOVES2014, TTI used MOVES default start per vehicle (which varied only by MOVES day type) in combination with local vehicle populations to estimate vehicle starts activity. In MOVES3, vehicle starts per hour also vary by county (because age distributions also vary by county).

For each hour of the day, the starts per vehicle data calculated by the MOVES algorithm were multiplied by the local vehicle type population estimates to produce the total number of starts by vehicle type per hour.

The starts per vehicle data were used with constant vehicle type populations (i.e., vehicle type populations were assumed to be constant throughout the calendar year).

3.7 Hotelling, SHEI and APU Hours

Hotelling hours were calculated for heavy-duty, long-haul trucks only (i.e., SUT 62[12]) in several steps. First total hotelling hours were calculated using information from a TCEQ extended idling study (TTI, 2019). Scaling factors were then used to convert these base hotelling hours to those relevant to the analysis scenario (defined by analysis year, season, and day type), which were then allocated to each hour of the day. Estimations were then made of the proportions of hotelling hours that occur in each of the four hotelling categories: idling using the main engine (SHEI), idling using a diesel APU, idling using an electric APU, or idling with no engine or auxiliary power[13].

3.7.1 24-Hour Hotelling

County-level hotelling scaling factors were developed to transform base, 2017 winter weekday, total daily hotelling hours to daily hotelling hours for the EIs. Scaling factors were calculated using the ratio of heavy-duty long haul VMT for a 2017 winter weekday relative to heavy-duty long haul VMT for each EI scenario (e.g., analysis seasonal weekday SUT 62 VMT divided by base 2017 winter weekday SUT 62 VMT).

Total daily hotelling for each county in the EI scenario was calculated by multiplying the appropriate scaling factor by the total daily hotelling hours contained in the 2017 winter weekday total daily hotelling hours study.

3.7.2 Hotelling by Hour

Hotelling by hour was estimated by allocating daily hotelling hours to each hour of the day as a function of the inverse of the EI hourly VHT fractions for SUT 62. The hourly VHT fractions were calculated using the hourly VHT from the SHP estimation process (VHT = SHO). The inverses of these hourly VHT fractions were calculated and then

[12] SUT 62 represents long-haul combination trucks, for which only diesel fuel types are modeled.

[13] Note that only SHEI and APU diesel hotelling operating modes generate emissions. The other fractions are calculated for completeness.

normalized across all hours to produce the county-level, hotelling hours hourly distribution. If the hourly hotelling hours (as calculated above) were greater than SHP (for SUT 62), the final hotelling hours estimate was set equal to the SHP.

3.7.3 SHEI and APU Hours

The hourly, county-level, hotelling estimates were then factored to calculate SHEI and diesel APU hours activity components using extended idle and APU fractions. The SHEI and APU hour fractions were obtained using the MOVES default hotelling activity distribution by SUT 62 model year. The MOVES SHEI and APU hotelling distributions[14] are shown in Table 15. Note that only SHEI (operating mode ID 200) and diesel APU hours (operating mode ID 201) are used to calculate emissions.

Table 15. Hotelling Activity Distributions by Model Year.

First Model Year	Last Model Year	200 ExtendIdling	201 Diesel Aux	203 Battery AC	204 APU Off
1960	2009	0.80	0	0	0.20
2010	2020	0.73	0.07	0	0.20
2021	2023	0.48	0.24	0.08	0.20
2024	2026	0.40	0.32	0.08	0.20
2027	2050	0.36	0.32	0.12	0.20

3.8 Estimation of Summer Weekday Off-Network Vehicle Activity

The 24-hour aggregate summer weekday emissions inventory calculations required 24-hour aggregate summer weekday off-network activity estimates by vehicle category and MOVES road type for each county and analysis year. The following sections describe the details for estimation of 24-hour aggregate summer weekday off-network activity for each county in each analysis year in Appendix F.

3.8.1 Estimation of 24-Hour Summer Weekday ONI

The first activity measure needed to estimate the off-network emissions using the mass per activity emission rates are county-level analysis year summer weekday 24-hour estimates of ONI by vehicle type. In each analysis year, for each hour, the county-level summer weekday vehicle category ONI was calculated using the formula shown

[14] Current MOVES3 defaults (also used in the TCEQ 2017 truck extended idling study).

in Section 3.4, using summer weekday SHO and summer weekday averaged total idle fractions. The hourly ONI estimates by vehicle category were calculated for each county and year and summed to 24-hour totals for input to the emissions calculations. The vehicle category summer weekday ONI estimates by county and year were provided in the inventory data summaries in Appendix F.

3.8.2 Estimation of 24-Hour Summer Weekday Adjusted SHP

The second activity measure needed to estimate the off-network emissions using the mass per activity emission rates are county-level analysis year summer weekday 24-hour estimates of Adjusted SHP by vehicle type. In each analysis year, for each hour, the county-level summer weekday vehicle category Adjusted SHP was calculated as described in Section 3.5 using summer weekday source hours, SHO and ONI. The summer weekday adjusted SHP estimates by vehicle category were calculated for each county and analysis year and summed to 24-hour totals for input to the emissions calculations. The vehicle category summer weekday adjusted SHP estimates by county and year were provided in the inventory data summaries in Appendix F.

3.8.3 Estimation of 24-Hour Summer Weekday Starts

The third activity measure needed to estimate the off-network emission using the mass per activity emission rates are county-level analysis year summer weekday 24-hour estimates of vehicle starts by hour and vehicle type. The summer weekday hourly starts per vehicle were calculated as described in Section 3.6 using local age distributions and avft inputs to MOVES combined with MOVES default parameters (startsageadjustment, startsmonthadjust [three-month seasonal average for summer weekday scenario], and startspervehicle). The vehicle type hourly calculated starts per vehicle were multiplied by the analysis year county-level vehicle type vehicle population to estimate the county vehicle type starts by hour, which were summed to the 24-hour period for input to the emissions calculations. The 24-hour summaries of the county vehicle category starts for each analysis year were included in the Appendix F.

3.8.4 Estimation of 24-Hour Summer Weekday SHEI and APU Hours

The remaining activity measure needed to estimate summer weekday off-network emission using the mass per activity emission rates are county-level analysis year summer weekday 24-hour estimates of heavy-duty diesel truck (SUT 62) SHEI and APU hours. The 2017 winter weekday extended idling estimates for each Texas county from a TCEQ extended idling study were used to calculate the hotelling scaling factors by dividing analysis year summer weekday 24-hour SUT 62 VMT by the base scenario 24-hour SUT 62 VMT. Hotelling hourly factors, inverse of VMT hourly fractions, were then applied to allocate the 24-hour hotelling by analysis year to each hour of the day. To ensure that valid hourly hotelling values are used, the hourly hotelling activity was compared to the SUT 62 hourly SHP (i.e., hourly hotelling values cannot exceed the hourly SHP values). MOVES default model year based SHEI and APU hours factors were then applied to the hotelling hours in each hour-of-day to produce the hourly SHEI and APU hours of activity. The hourly estimates were aggregated to 24-hour totals for input to the summer weekday emissions calculations. The 24-hour summaries of the county-level estimates of summer weekday hotelling hours, SHEI, and APU hours for each analysis year were included in the inventory data provided electronically in Appendix F.

3.9 Estimation of Annual Off-Network Vehicle Activity

To estimate the annual emissions in a consistent manner, the annual average daily off-network activity was calculated the same as the summer weekday activity without seasonal adjustment factors. The annual off-network vehicle activity estimates were calculated from annual average daily off-network vehicle activity estimates multiplied by 365 days per analysis year. The following sections describe the details for estimation of annual off-network activity for each county in each analysis year provided electronically in Appendix F.

3.9.1 Estimation of Annual ONI

The first activity measure needed to estimate the off-network emissions using the mass per activity emission rates are county-level analysis year annual estimates of ONI by vehicle type. In each analysis year, for each hour, the county-level annual average daily vehicle category ONI was calculated using the formula shown in Section 3.4 and AADT based SHO and 12-month averaged total idle fractions. The hourly ONI estimates by vehicle category were calculated for each county and year and summed to 24-hour AADT totals and multiplied by 365 days per analysis year for input to the annual emissions calculations. The vehicle category annual ONI estimates by county and year were provided in the inventory data summaries in Appendix F.

3.9.2 Estimation of Annual Adjusted SHP

The second activity measure needed to estimate the off-network emissions using the mass per activity emission rates are county-level analysis year annual estimates of Adjusted SHP by vehicle type. In each analysis year, for each hour, the county-level annual average daily vehicle category Adjusted SHP was calculated as described in Section 3.5 using AADT based source hours, SHO and ONI. The hourly adjusted SHP estimates by vehicle category were calculated for each county and analysis year and summed to 24-hour totals and multiplied by 365 days per analysis year for input to the annual emissions calculations. The vehicle category annual adjusted SHP estimates by county and year were provided in the inventory data summaries in Appendix F.

3.9.3 Estimation of Annual Starts

The third activity measure needed to estimate the off-network emission using the mass per activity emission rates are county-level analysis year annual estimates of vehicle starts by vehicle type. The annual average daily hourly starts per vehicle were calculated as described in Section 3.6 using local age distributions and avft inputs to MOVES combined with MOVES default parameters (startsageadjustment, startsmonthadjust [12-month average for annual scenario], and startspervehicle). The vehicle type hourly calculated starts per vehicle were multiplied by the analysis year county-level vehicle type vehicle population to estimate the county vehicle type starts by hour, which were summed to the 24-hour period and multiplied by 365 days per analysis year for input to the emissions calculations. The annual summaries of the county vehicle category starts for each analysis year were included in the inventory data provided in Appendix F.

3.9.4 Estimation of Annual SHEI and APU Hours

The remaining activity measure needed to estimate annual off-network emission using the mass per activity emission rates are county-level analysis year annual estimates of heavy-duty diesel truck (SUT 62) SHEI and APU hours. The 2017 winter weekday hotelling hours estimates for each Texas county from a TCEQ extended idling study were used with hotelling scaling factors (calculated by dividing analysis year annual average daily 24-hour SUT 62 VMT by the base scenario 24-hour SUT 62 VMT) to produce analysis year hotelling hours estimates. Annual average daily hotelling hourly factors, inverse of VMT hourly fractions, were then applied to allocate the 24-hour hotelling by analysis year to each hour of the day. To ensure that valid hourly hotelling values are used, the hourly hotelling activity was compared to the CLhT_Diesel hourly SHP (i.e., hourly hotelling values cannot exceed the hourly SHP values). MOVES default model year based SHEI and APU hours factors were then applied to the hotelling hours in each hour-of-day to produce the hourly SHEI and APU hours of activity. The hourly estimates were aggregated to 24-hour totals and multiplied by 365 days per analysis year for input to the annual emissions calculations. The annual summaries of the county-level estimates of hotelling hours, SHEI, and APU hours for each analysis year were included in the inventory data provided electronically in Appendix F.

3.10 Estimation of Off-network Activity Inputs for MOVES CDB Tables

The source type population and off-network activity tables needed in the CDBs consisted of the following tables on vehicle population, starts, and heavy-duty truck hoteling input data, along with various off-network activity allocation factors. The CDB input tables derived from the estimation of off-network activity are:

- sourcetypeyear (analysis year source type population estimates for the county)
- hotellinghoursperday (total hotelling hours for the county by day type)
- hotellingmonthadjust (factor to adjust hotelling hours per day up or down between months)
- hotellinghourfraction (fractions by day type for distributing hotelling hours per day to each hour of the day)
- startsmonthadjust (factor to adjust starts per day up or down between months)

The county-level sourcetypeyear tables were created based on 2018 vehicle registration data and applying a VPGF for all counties in all analysis years.

The county-level hotellinghoursperday tables were created using 2017 winter weekday information from a TCEQ extended idling study with scaling factors (dividing analysis year annual average daily 24-hour SUT 62 VMT by the base scenario 24-hour SUT 62 VMT) for all counties in all analysis years.

The zone-level (county-level) hotellingmonthadjust tables were created using the information from monthvmtfraction tables developed in Section 2.7 and multiplied by 12 (to all fraction values).

The zone-level (county-level) hotellinghourfraction tables were created using the hourvmtfraction tables developed in Section 2.7. The hotelling hour fractions were calculated as the weighted ratio of inverse of hourly VMT fractions in each hour.

The TxDOT district-level startsmonthadjust tables were created using using the information from monthvmtfraction tables developed in Section 2.7 and multiplied by 12 (to all fraction values), except for motorcycles for which the MOVES default was used.

4 INPUTS DEVELOPMENT FOR MOVES CDBS

One set of MOVES input CDBs, constituting one for each Texas county (254) and each MOVES analysis year (63) for a total of 16,002, was produced as a major project deliverable, as described in this section. . These individual county CDBs may be input to MOVES county scale runs, with appropreate MRS settings, to produce EI results for various scenarios (e.g., day type, season, calendar year).

A subset of these CDBs (up to 36 to 44 county group CDBs for each analysis year) was selected and used for the production of MOVES emissions rate inputs (described in Section 5) to the external summer weekday and annual trend EI calculations.

The following sections provide a listing of the CDB tables used and information on data sources and input data development.

4.1 MOVES CDB Tables and Data Sources

Table 16 lists the 32 MOVES input data tables included in each CDB, brief descriptions, and information on input data, such as locally developed, MOVES defaults, or a combination of both. Note that some of the MOVES tables provide information by zone. In this analysis, zone is the same as a county.

Table 16. MOVES CDB Tables with Input Data Sources and Descriptions

MOVES Table	Data Source	Notes
auditlog	MOVES default	I/M records conditions from MOVES default database. Flag is inserted when imcoverage table is empty.
avft	Local / MOVES default	Set for Texas modeling assumptions, i.e., gasoline and diesel only, but also including default flex fuel vehicle fractions which were set to 100% gasoline use via the fuelusagefraction table
avgspeeddistribution	MOVES default	Driving time fractions by speed bin for each source type, road type, day type, hour.
county	Local	Identifies the county, barometric pressure (TxDOT district level for county group CDBs), high or low altitude, and whether the county is an Metropolitan Statistical Area (MSA) or non-MSA county.
countyyear	Empty table used	Stage II refueling control program adjustments are typically set to zero to reflect the program is no longer in effect. However refueling emissions were not modeled and this table was left empty.
dayofanyweek	MOVES default	MOVES default dayofanyweek table is used.
dayvmtfraction	Local	Locala weekend and weekday period VMT fractions by month for each source type and road type.
fuelsupply	Local	Market shares of fuel formulations set to reflect Texas modeling assumptions of gasoline and diesel only, although all MOVES default fuels were included as required to run MOVES3 (i.e., CNG,

MOVES Table	Data Source	Notes
		E85, and electric are included but are not used as specified in the Alternate Vehicle and Fuel Technology (AVFT) and fuel usage configurations) monthID 1 data for months 1-3, 11-12; monthID 7 data for months 5-9; shoulder fuel for months 4, 10.
fuelformulation	Local / MOVES default	Gasoline and diesel formulations by fuel region based on MOVES defaults, adjusted as needed to better reflect Texas information. (with MOVES default Compressed Natural Gas (CNG), E85, and electric as required to run MOVES3)
fuelusagefraction	Local	Flex fuel vehicle fuel type usage, set for Texas modeling assumptions, i.e., flex-fuel vehicles operate totally on gasoline.
hotellingactivitydistribution	MOVES default	Allocation of hotelling to four operating modes by zone (e.g., county) and model year group.
hotellingagefraction	Empty table used	Hourly hotelling distribution by age for each zone and day type – included to preempt commandline execution errors.
hotellinghourfraction	Local	Inverse ratio of local hourvmtfraction.
hotellinghoursperday	Local	Local data scaled from VMT based on 2017 winter weekday scenario hotelling hours.
hotellingmonthadjust	Local	Month VMT fraction by source type[12].
hourvmtfraction	Local	Hourly VMT fractions for each source type, road type, day type.
hpmsvtypeyear	Local	Historic and forecasted local data by HPMS vehicle type.
imcoverage	Local	Empty for non-I/M counties, or includes I/M program modeling parameters characterizing the local program applicable to the county, with updated compliance factors based on TCEQ area-specific I/M program statistics.
monthofanyyear	MOVES default	Month of year.
monthvmtfraction	Local and MOVES default	Local month VMT fractions by source type, except for source type 11. MOVES default source type 11 month VMT fractions are used.
roadtypedistribution	MOVES default	Source type VMT fractions by MOVES road type.
sourcetypeagedistribution	Local/MOVES default	Distribution by 31 age categories for each source type, based on 2018 county vehicle registrations. (TxDOT district level for county group CDBs), and MOVES defaults where needed (i.e., for buses, refuse trucks, motor homes)
sourcetypeyear	Local	Historic and forecasted local vehicle population data based on 2018 vehicle registration data and scaled by the ratio of scenario VMT and base scenario. (2018 summer weekday scenario) VMT
startshourfraction	MOVES default	Average hourly allocation of starts by source type and day type.
startsmonthadjust	MOVES default /Local	Average monthly multiplicative adjustment to startspervehicleperday, monthvmtfraction table*[12] and MOVES default for motorcycle.
startsperdaypervehicle	MOVES default	Average starts per day by source type and day type.
state	MOVES default	Identifies the state and idle region. (102 for Texas)
totalidlefraction	MOVES default	Ratio of total SHI and total SHO for each source type by month, day type, idle region, county type. (MSA or non-MSA)

MOVES Table	Data Source	Notes
year	MOVES default	Designates analysis year as base year. (i.e., activity inputs supplied, not forecast by MOVES)
zone	MOVES default (set factors = 1)	SHO geographic allocation factors, set to 1.0 for county scale runs.
zonemonthhour	Local	Meteorological inputs for 12 months. (winter = 12, 1, 2; spring = 3, 4, 5; summer = 6, 7, 8; fall = 9, 10, 11). Provides hourly temperatures and relative humidity by county. (seasonal averages provided by TCEQ, based on 2019 weather station data)
zoneroadtype	MOVES default (set factors = 1)	Road type VMT allocation factors to county road type VMT, set to 1.0 for county scale runs.

4.2 Development of CDB Table Input Data

The following sections provide details on the development of the local inputs and MOVES defaults used in the CDBs product, such as for temporal and geographical information, vehicle activity and populations, fleet characteristics, meteorological, fuels, and I/M programs. The MOVES defaults used were from the MOVES3.0.3 database "movesdb20220105".

4.2.1 Temporal and Geographical Information Inputs

The following five mostly informational tables define the analysis year, months, weeks (in terms of weekday versus weekend day portions), state, and county of the analysis:

- year
- monthofanyyear
- dayofanyweek
- state
- county

All the inputs to these tables were MOVES defaults, except for barometric pressure, in the county table, which is local input data.

The "year", "monthofanyyear", and "dayofanyweek" input tables define the analysis year and the associated months and weeks. The yearID field of the "year" table was populated with the analysis year value, and the analysis year was set as a base year (to specify that certain user-input fleet and activity data were to be used, rather than forecast by MOVES during the model runs). As part of designating the appropriate fuel supply for the modeling run, the fuelyearID in the year table was also set to the analysis year. The monthofanyyear table information includes month IDs (i.e., 1 – 12), month names (i.e., January – December), and the number of days in each month. The dayofanyweek table information defines a week as composed of two day-types with the specified day quantities of "5" and "2", for weekdays and weekend days, respectively.

The "state" table was populated with the Texas state ID, name, abbreviation, and idle region ID. In addition to identifying the county of analysis (with county ID, state ID, county name, altitude, and county type [MSA or non-MSA]), the "county" table contains local barometric pressure information (discussed later with meteorological inputs).

4.2.2 Activity and Vehicle Population Inputs

A combination of local and default data was used for the on-network and off-network vehicle activity and allocation factor inputs and vehicle population inputs.

4.2.2.1On-network Activity

The on-network activity tables included those needed for the county's annual VMT and several VMT and SHO allocation factors. These CDB input tables are:

- hpmsvtypeyear (county, analysis year, annual VMT by HPMS vehicle class)
- monthvmtfraction (fraction of annual VMT for each month by source type)
- roadtypedistribution (fraction of VMT for each road type by source type)
- dayvmtfraction (fraction of monthly VMT for each day type by source type and road type)
- hourvmtfraction (fraction of day type VMT for each hour of the day by source type and road type)
- avgspeeddistribution (fraction of SHO for each of 16 MOVES average speed bins by source type, road type, day type, and hour)
- zoneroadtype (allocation factors of total SHO, for each road type, between counties)

All the inputs to these tables were based on local data, except for the roadtypedistribution and avgspeeddistribution inputs, which were MOVES defaults.

The annual VMT input estimates for each county and analysis year, and the month, day type, and hour VMT fractions were developed using local data and standard procedures as more fully described in Section 2.

The zoneroadtype table inputs were set as required for distributing total road type SHO between counties. Since when using MOVES county scale mode only one county is modeled per run, these allocation factors were set to 1.0.

4.2.2.2 Off-network Activity and Vehicle Populations

The source type population and off-network activity tables needed in the CDBs consisted of the following tables on vehicle population, starts, and heavy-duty truck hoteling input data, along with various off-network activity allocation factors:

- sourcetypeyear (analysis year source type population estimates for the county)
- hotellinghoursperday (total hotelling hours for the county by day type)
- hotellingmonthadjust (factor to adjust hotelling hours per day up or down between months)
- hotellinghourfraction (fractions by day type for distributing hotelling hours per day to each hour of the day)
- hotellingactivitydistribution (factors for allocating total hotelling hours to the four hotelling operating modes, by model year)
- startsperdaypervehicle (starts per day by source type for each day type)
- startsmonthadjust (factor to adjust starts per day up or down between months)
- startshourfraction (fraction of starts for each day type by the hour and source type)
- zone (allocation factors for starts, idling, and parking between counties)

Source-type population inputs were developed for all counties and analysis years using local data and standard procedures as previously described in Section 3.

For hotelling, local inputs were developed and used for hotelling hours per day, the month adjustments, and the hourly distributions, were developed as previously described in Section 3. The MOVES default was used for the hotelling activity distribution input.

For vehicle starts, the month adjustment inputs were based on local VMT month adjustment data except motorcycles used the MOVES defaults, as previously described in Section 3. The MOVES defaults were also used for the starts per vehicle per day and start hourly distributions.

The zone table inputs were set as required for distributing off-network activity (starts, idling, parking) between zones (counties). Since when using the MOVES county scale only one county is modeled per run, these allocation factors were set to 1.0.

4.2.3 Fleet Characteristics Inputs

Local age distributions, or age fractions for each SUT, and local fuel fractions by model year (or technology), were used, in conjunction with MOVES defaults as needed. The MOVES tables for these inputs are:

- sourcetypeagedistribution (analysis year age fractions for each of 31 age IDs [0-30], by source type)
- avft (fuel fractions for each MOVES fuel type and engine technology, by source type and model year)

These data were sourced from TxDMV 2018 year-end registration data aggregated for each TxDOT district, for age distributions, and at the state level, for fuel fractions. The age distributions and fuel engine fractions inputs were calculated and written to text files in preparation for loading the data into the appropriate CDB input tables: the sourcetypeagedistribution table for age distributions and the avft table for fuel engine fractions. MySQL scripts were used to populate the CDB input tables.

The local TxDMV registration data provides fuel type fractions (proportion of gasoline or diesel-powered vehicles) for heavy-duty vehicles but not for light-duty vehicles. MOVES default fuel fractions were therefore applied to estimate light-duty fuel fractions, as well as fuel fractions for buses, refuse trucks, and motor homes. Only gasoline and diesel vehicles were explicitly included in the CDBs.

Table 17 summarizes the data sources and aggregation levels used to estimate the local sourcetypeagedistribution and AVFT inputs to MOVES.

Table 17. Sources and Aggregations for Age Distributions and Fuel Fractions.

SUT Name	SUT ID	TxDMV Category[1] Aggregations for Age Distributions and Fuel/Engine Fractions	Geographic Aggregation for Age Distributions[2]	Geographic Aggregation for Fuel/Engine Fractions[3]
Motorcycle	11	Motorcycles	TxDOT district	NA – 100% gasoline, no Fuel/Engine Fractions
Passenger Car	21	Passenger Cars	TxDOT district	MOVES default[2]
Passenger Truck	31	Total Trucks<=8500	TxDOT district	MOVES default[2]
Light Commercial Truck	32	Total Trucks<=8500	TxDOT district	MOVES default[2]
Single-Unit Short-Haul Truck	52	>8500+ >10000+ >14000+>16000	TxDOT district	Texas Statewide
Single-Unit Long-Haul Truck	53	>8500+ >10000+ >14000+>16000	Texas Statewide	Texas Statewide
Refuse Truck	51	MOVES default	MOVES default	MOVES default
Motor Home	54	MOVES default	MOVES default	MOVES default
Other Buses	41	MOVES default	MOVES default	MOVES default
Transit Bus[2]	42	MOVES default	MOVES default	MOVES default
School Bus	43	MOVES default	MOVES default	MOVES default
Combination Short-Haul Truck	61	>19500+ >26000+ >33000+ >60000	TxDOT district	Texas Statewide
Combination Long-Haul Truck	62	>19500+ >26000+ >33000+ >60000	Texas Statewide	NA – 100 % diesel, no Fuel/Engine Fractions

[1] TxDMV year-end 2018 (latest available, used for all years) county vehicle registration data were used for developing local inputs (weights are gross vehicle weight ratings in units of pounds). The MOVES model default age distributions were from the MOVES3.0.3 database (movesdb20220105).

[2] For long-haul truck age distributions statewide registration aggregations were used, whereas for other source types TxDOT district-level aggregations were used with MOVES defaults, as needed.

[3] MOVES fuel engine fraction defaults (for gasoline, diesel, E85 capability) were used for light-duty SUTs (with E85 use set to zero in the MOVES fuelusagefraction table), and for refuse trucks, motor homes, and buses.

4.2.4 Meteorological Inputs

TTI developed the meteorological inputs to MOVES by replicating and refining the method and procedures put in place by TCEQ for Texas statewide, county-level emissions inventory development. TxDOT district and county-level meteorological inputs were prepared by month for all TxDOT districts and 50 individual metropolitan counties. The MOVES tables for these inputs are:

- county (contains barometric pressure and altitude inputs for the county, among other county information items)
- zonemonthhour (contains hourly average temperature and relative humidity inputs by month for the county)

TTI produced the hourly temperature, hourly relative humidity, and 24-hour barometric pressure averages using readily available 2019 calendar year hourly data (originally acquired from TCEQ for use in the 2020 Air Emissions Reporting Requirements (AERR) EIs) from numerous weather stations within each district and county. Since the El Paso District spans two time zones (Mountain and Central), it was divided into two separate data sets by time zone.

The MOVES zonemonthhour table uses the standard month numbers as month IDs - 1 through 12 as January through December - which were assigned to the monthly hourly averages data.

The MOVES county table was populated with annual average barometric pressure estimates for annual scenario and summer weekday barometric pressure for summer weekday scenario. Altitude, also a MOVES county table input, was set to “low” for all counties.

Both sets of meteorological data were used, one based on county-level data and one based on district-level data. TTI assigned the county-level estimates to the 50 metropolitan area counties for which the individual county estimates were developed under the method. For the remaining, less urban counties, their associated district-level meteorological inputs were assigned. All the necessary meteorological inputs in MOVES-specified formats were combined in a database for use in building the CDBs for all 254 counties.

The meteorological inputs to MOVES are available in Appendix G.

4.2.5 Fuels Inputs

This section provides details on the development of the Texas fuel formulation, fuel supply, and flex-fuel vehicle fuel usage CDB inputs to MOVES. After an overview, predominant Texas fuel types, data sources, and the general procedure are detailed. Databases of the finalized fuel formulation and fuel supply data used to populate the CDBs were provided in the electronic data submittal (Appendix B).

4.2.5.1 Overview and Assumptions

TTI used the MOVES default Texas gasoline and diesel fuel data as reasonable representations of Texas seasonal fuel trends, with some adjustments based on local information to better reflect Texas fuels. (The MOVES alternative fuel types were considered negligible in terms of market share in Texas and were not modeled.)

The MOVES fuels input tables used are:

- fuelsupply (market share fractions – for each fuel subtype formulation, month, year, and fuel region – must sum to 1.0 for each MOVES fuel type, month, year, and region)
- fuelformulation (fuel formulation ID, fuel subtype ID, and fuel properties, for each fuel formulation specified in the fuelsupply table for the modeling run)
- fuelusagefraction (gasoline and E85 [ethanol blended with about 15 percent gasoline] use fractions for flex-fuel capable vehicles, for the county and year)

The inputs of these three tables require consistency with the AVFT table input data (fuel fractions for each source type by model year), which, as previously detailed, was set to model only gasoline, diesel, and flex-fuel vehicle capability for Texas. Further, to model gasoline and diesel only, flex-fuel capable vehicles were set to 100 percent gasoline use in the fuelusagefraction table; fuel properties and market shares for gasoline and diesel were specified in the fuelformulation and fuelsupply tables.15

Geographically, MOVES assigns fuel supplies (market shares) via the fuel supply table to counties by association with fuel regions, each of which may consist of one or more counties, and which are defined by fuel rule jurisdictions and/or distribution networks. Temporally, MOVES assigns fuel formulations, as also specified in the fuel supply table, to fuel years and month groups (synonymous with the years and months in MOVES). Table 18 shows the MOVES fuel regions for Texas, for 1990 and for later years, with brief details on fuel rules (and/or distribution networks involved) and affected counties.

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[15] A requirement with MOVES3 is inclusion of all MOVES on-road fuel types (gasoline, diesel, E85, CNG, electricity) in the MOVES modeling run files (i.e., MOVES run specification files, fuel formulation tables, and fuel supply tables), regardless of the local inventory scope. Alternative fuel types were included in these files, but were set for non-use in the AVFT and flex fuel vehicle use tables.

Table 18. Texas Fuel Regions in MOVES

<table>
<tr><th>Year</th><th>MOVES fuel region ID</th><th>TTI code</th><th>Counties[1]</th><th>Defining Rule Description[2]</th></tr>
<tr><td rowspan="6">1999 to 2060</td><td>300000000</td><td>R1</td><td>132 (Western)</td><td>Federal 9.0 RVP limit (RVP waiver available for E10)</td></tr>
<tr><td>178010000</td><td>R2</td><td>95 (Central, Eastern)</td><td>State 7.8 RVP limit (no RVP waiver)</td></tr>
<tr><td>370010000</td><td>R3</td><td>1 (El Paso)</td><td>State 7.0 RVP (no RVP waiver)</td></tr>
<tr><td>1370011000</td><td>R4</td><td>12 (DFW, HGB)</td><td>RFG</td></tr>
<tr><td>178000000</td><td>R5</td><td>3 (BPA)</td><td>Federal 7.8 RVP limit (RVP waiver okay for E10)</td></tr>
<tr><td>100000000</td><td>R6</td><td>11 (Southern)</td><td>Same as for R1, except for the distribution network</td></tr>
<tr><td rowspan="2">1990</td><td>300000000</td><td>R1 R3</td><td>133 (Western)</td><td>Federal 9.0 RVP limit all counties</td></tr>
<tr><td>100000000</td><td>R2 R4 R5 R6</td><td>121 (Eastern, Southern)</td><td>Federal 9.0 RVP limit all counties</td></tr>
</table>

[1] RFG counties include DFW - Dallas, Denton, Collin, and Tarrant; and HGB - Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller. Beaumont–Port Arthur (BPA) counties are Hardin, Jefferson, and Orange.
[2] See https://www.tceq.texas.gov/airquality/mobilesource/vetech/fuelprograms.html#rvp1 for the list of 95 Texas counties under the State 7.8 RVP limit rule. Note - R2, R4, R5, and R6 counties also require TxLED fuel (October 2005 start), the effects of which must be incorporated via post-processing of MOVES output.

The MOVES fuel formulations between summer and winter and for the two transitional periods (shoulders) are defined as:

- Summer: May - September (month IDs 5, 6, 7, 8, 9)
- Winter: January – March, November, and December (month IDs 11, 12, 1, 2, 3)
- Shoulders: April and October (month IDs 4, 10)

Table 19 lists all the on-road fuel types available in MOVES. The associated fuel subtypes for which the MOVES database contains actual, default fuel formulations and market shares (by region, year, and month) are listed in Table 20.

Table 19. MOVES On-road Fuel Types

Fuel Type ID	Description	Modeled
1	Gasoline	Yes
2	Diesel Fuel	Yes
3	CNG	No
5	Ethanol (E85)	No
9	Electricity	No

Table 20. MOVES3 Fuel Subtypes with Available (Default) Market Shares by Year

Fuel Subtype ID	Description	Fuel Type ID	Fuel Subtype Market Share Information
10	Conventional Gasoline (CG)	1	1990: 100% 1999 – 2011: phasing out 2012 – 2060: 0%
12	Gasohol (E10[1] – CG blend)	1	1990: 0% 1999-2011: phasing in 2012- 2060: 100%
12	Gasohol (E10[1] – RFG blend)	1	1990: 0% 1999-2060: 100%
20	Conventional Diesel Fuel	2	1990-2010: 100% 2011-2060: 0%
21	Biodiesel (BD3.4)	2	1990-2010: 0% 2011-2060: 100%
30	CNG	3	All Years: 100%
51	Ethanol (E85)	5	All Years: 100%
90	Electricity	9	All Years: 100%

[1] Depending on the other fuel properties, E10 may be either CG or RFG.

As shown in Table 20, MOVES contains two gasoline and two diesel fuel subtypes with actual market shares, and a single fuel subtype each for CNG, E85, and electricity. The CG (non-oxygenated) subtype is phased out from 100 percent market share in 1990 to zero market share in 2012 when the market is assumed saturated by E10; conversely, the E10 gasoline subtype is phased in from zero market share in 1990 to 100 percent market share in 2012, when it completely replaces the CG subtype. From 1999 through 2011, gasoline fuel type market shares for the CG and E10 subtypes are each less than 1.0 but combined are equal to 1.0, with market shares decreasing for CG and increasing for E10.

Additional fuel subtypes are defined in MOVES (such as different gasoline/ethanol blends, or gasohols, like E5, E8, E15, etc.), but currently, MOVES does not include any actual fuel supplies (market shares) for these other subtypes.

4.2.5.2 Texas Fuel Type Details

Texas complies with the various federal and state fuel controls that vary by region (county groups), for example, as previously shown in Table 18. Table 21 provides a more comprehensive listing of fuel rules applicable in Texas over the Trends analysis period, which MOVES, for the most part, incorporates the effects of.

Table 21. Federal and State Fuels Controls in Texas during Trend Analysis Period.

Program	Start	Control/Standard	Geographic Coverage
Federal Controls on Gasoline Volatility[1]	1990	Max summertime RVP, 9.0 pounds per square inch (psi)	All 254 counties.
Federal Controls on Gasoline Volatility[1]	1992	Max summertime RVP, 7.8 psi Max summertime RVP, 9.0 psi	1-hr ozone counties[2] Remainder of state
El Paso Oxygenated Gasoline[3]	1992	Winter control period minimum weight percent oxygen 2.7%	El Paso CO nonattainment county
Federal RFG[4]	Phase I 1995	Performance standard reductions: VOC, Toxics	DFW and HGB 1-hr ozone nonattainment counties
El Paso Low RVP[5]	1996	Max summertime RVP, 7.0 psi	El Paso County
Federal RFG	Phase II 2000	Performance standard reductions: VOC, NO_x, Toxics	DFW and HGB 1-hr ozone nonattainment counties
Regional Low RVP[6]	2000	Max summertime RVP, 7.8 psi	95 Texas counties[6]
Tier 2 Low Sulfur Gasoline[7]	2004-2006 phase in	Refinery 30 ppm annual average, 80 ppm refinery gate, and 95 ppm downstream per-gallon caps	National
Federal Low Sulfur Highway Diesel	1993 2006	500 ppm max[8] 15 ppm max, with provisions[9]	National
TxLED [10]	2005	Low aromatic HC and high cetane number to control NO_x	110 counties: 95 counties and 15 1-hr ozone counties
National Renewable Fuel Standard[11]	2006	Renewable fuel in gasoline and diesel transportation fuels, produced/imported	National
Mobile Source Air Toxics Rule[12]	2011	Gasoline benzene limit: 0.62 volume % annual average; 1.3 volume % maximum annual average (2012)	National
Tier 3 Low Sulfur Gasoline[13]	2017-2020 phase in	Refinery 10 ppm annual average, maintains Tier 2 caps	National

[1] 40 CFR § 80.27. Controls and Prohibitions on Gasoline Volatility.
[2] BPA: Hardin, Jefferson, Orange; DFW: Collin, Denton, Dallas, Tarrant; HGB: Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, Waller; and El Paso County.
[3] 30 TAC § 114.100 Oxygenated Fuels.
[4] 40 CFR § 80.41 Standards and Requirements for Compliance (federal RFG).
[5] 30 TAC §§ 115.252. Control Requirements (for gasoline RVP).
[6] 30 TAC § 114.301. Control Requirements for RVP. See the rule for a list of 95 central and eastern Texas counties.
[7] Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule, EPA, February 10, 2000. Note that the typical pre-control average sulfur content is about 300 ppm.
[8] 40 CFR § 80.29. Controls and Prohibitions on Diesel Fuel Quality. (Prior years unregulated.)
[9] 40 CFR § 80.500. What are the Implementation Dates for the Motor Vehicle Diesel Fuel Sulfur Control Program?; 40 CFR § 80.520. What are the Standards and Dye Requirements for Motor Vehicle Diesel Fuel?
[10] 30 TAC § 114.312-319. Low Emission Diesel (LED) Standards. Covers 95 Regional Low RVP and 1-hr ozone counties.
[11] 40 CFR § 80.1100 Subpart K — Renewable Fuel Standard. Renewable fuels reduce the fossil fuel in motor vehicle fuel (produced from grain, starch, oil seeds, vegetable, animal, or fish materials; or natural gas produced from a biogas source.)
[12] Control of Hazardous Air Pollutants From Mobile Sources; Final Rule, EPA, 2007.
[13] Control of Air Pollution From Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, EPA, 2014.

The various controls or standards include limits on summertime gasoline volatility to reduce VOC; increasingly tightened gasoline and diesel sulfur standards to reduce PM; RFG emissions performance standards to reduce VOC, NO_x, and toxins; wintertime gasoline minimum oxygenate requirement to reduce CO; gasoline benzene limit to reduce benzene; renewable fuel standards promoting the consumption of domestically produced renewable fuels in place of imported petroleum; and Texas low emission diesel formulation for reducing NO_x (effects not available in MOVES, discussed later).

The MOVES gasoline and diesel defaults for the Texas fuel regions, by year and month, provide fairly reasonable estimates of fuel formulations and supplies reflective of the regulatory landscape for Texas fuels starting with 1990.

Based on a comparison of the MOVES fuel supply defaults for Texas and TCEQ fuel survey data summaries, TTI noted some updates to the MOVES defaults that would better reflect Texas fuels, such as regarding the use of gasoline oxygenates.

Texas retail gasoline survey data reveal a shift from ether-based oxygenates[16] to ethyl alcohol or ethanol in RFG in 2006. Ethanol was observed in conventional gasoline across Texas to varying degrees beginning in the summer of 2008. Observed ethanol volumes increased in Texas, and were assumed to have reached a saturation point (100% E10 gasoline across the state) in 2012 (based on TCEQ statewide summer 2011 and 2014 fuel survey summaries), consistent with the MOVES defaults.

MOVES does not model methyl tertiary butyl ether (MTBE) oxygenate blends. (MTBE was replaced with ethanol in oxygenate blends to provide an approximation of fuel effects over the range of analysis years.) To model, an equivalent oxygenate effect for MTBE, the ethanol volume percent with oxygen weight percent equivalent to that of the observed MTBE volume is used in place of MTBE. This however does not produce any MTBE emissions output that would have occurred and produces ethanol emissions when they would not have occurred.

In comparing the Texas fuel survey observations with MOVES fuel defaults, in light of MOVES limitations and the project scope, the following observations were made:

- For gasoline oxygenate blends, MOVES features only ethanol, thus, effects of other gasoline oxygenate blends as observed in Texas fuel surveys, such as MTBE (discontinued in Texas in 2006), are approximated using ethanol

[16] MTBE ethyl tertiary butyl ether, and tertiary amyl methyl ether.

- For CG counties, the MOVES E10 saturation year of 2012 is realistic for Texas, however, the Texas phase-in of E10 gasoline, with substantial market shares, began later (2008) than depicted in MOVES (1999)
- For RFG counties, MOVES RFG for 1999 and later years is E10, which is reflected in Texas RFG observations for 2006 and later years; Texas RFG survey summaries for 1999 through 2005 contain mainly ether-based oxygenate blends, although these blends are similar to the MOVES E10 RFG in terms of weight percent oxygen content
- MOVES default ester blend diesel (biodiesel) is B3.4 (diesel blended with 3.4 percent ester) nationally for all years starting with 2011 and later, based on national average Energy Information Administration (EIA) fuel consumption data (for 2011 through 2019), although data are available by state and year
- Gasoline and diesel sulfur standard phase-ins in MOVES adequately represent Texas observations

The alternative fuels available in MOVES3 were treated as negligible and excluded from the analysis (via the use of the MOVES AVFT, fuelusagefraction tables, and fuelfraction inputs). Since MOVES3 requires all (5) available fuel types in the model to be included in the fuelformulation and fuelsupply inputs, the MOVES3 default fuelformulations for the following—each with 1.0 market shares in the fuel supply—were also included in the CDBs.[17]

- CNG (fuelsubtypeid 30),
- E85 (ethanol - blended with roughly 15 percent gasoline - fuelsubtypeid 51),
- electricity (fuelsubtypeid 90).

4.2.5.3 Data Sources

The MOVES database (movesdb20220105) was the main source of the fuel formulation and supply data, supplemented with EIA data for biodiesel ester volumes, and updated as described in the next section, based on Texas fuel survey summary data collected at three-year intervals (i.e., 2005, 2008, 2011, 2014, 2017, and 2020) available from TCEQ.

[17] TTI inserted these alternative fuel formulations and supplies, and the updated AVFT fuel fractions [i.e., gasoline, diesel, and flex fuel types only], and set flex fuel vehicles to 100 percent gasoline use in the fuelusagefraction table, via CDB builder scripts.

4.2.5.4 General Procedure

Development of the fuel inputs involved updating the MOVES defaults based on the previously listed notes on the Texas information (rules, fuel survey summaries, and other information) versus the MOVES defaults for Texas.

The procedure for developing the inputs involved creating four databases, by trend year-group (i.e., 1990, 1999-2011, 2012-2019, 2020-2060), populating them with select MOVES default fuelsupply and fuelformulation data (e.g., by years, months, fuel types, and Texas fuel regions) and updating defaults to produce the final inputs for populating the CDBs.

MySQL scripts were written to create the databases with fuelformulation and fuelsupply tables, populate the tables with MOVES defaults, and modify the MOVES defaults where needed.

The following paragraphs summarize the adjustments to the MOVES defaults in preparing the fuels inputs by year-group, for gasoline, then diesel.

Gasoline

- **1990**: the straight MOVES defaults were used.
- **1999 – 2011**: for CG, changed the MOVES default start of the phase-in to E10 saturation (in 2012) from starting in 1999 to starting in 2008, by adjusting the market shares for CG and E10 accordingly (i.e., for 1999-2007, deleted E10 market shares and updated CG market shares to 1.0). Changed the El Paso winter oxygenate period fuel formulation and supply from the MOVES defaults (i.e., standard CG E10 phase-in) to a more appropriate oxygenate blend based on the state rule (i.e., equivalent of the minimum oxygen weight percent requirement), namely a 7.4 percent ethanol blend (MOVES fuel subtype E8 with subtype ID 13), covering the entire period (i.e., monthIDs 10, 11, 12, 1, 2, 3) with 1.0 market share. For RFG, the MOVES RFG default formulations and phase-in were unchanged.[18]
- **2012-2060**: For all six Texas MOVES fuel regions 100% E10 saturation was assumed in 2012, consistent with the MOVES defaults; E10 was maintained

[18] The MOVES RFG defaults for years 2000 through 2004 appeared to have reversed shoulder and winter formulations, as indicated by the shoulder month RVP values exceeding the winter RVP values. Typically, summer and winter RVP are the extremes. To correct, the shoulder formulations were used as winter formulations, and vice versa.

through 2060, along with the various other fuel property standard and limit implementations as indicated in Table 20. MOVES defaults were sufficient and used for all counties.

Diesel

- **1990 – 2010**: The MOVES defaults reasonably reflect the historical, conventional diesel sulfur levels and standard implementations, and were unchanged. The fuel subtype market share for the period was 100% (non-ester blend) conventional diesel.
- **2011 – 2060**: For the period, the diesel fuel subtype market share was 100 percent ultra-low sulfur biodiesel, consistent with the MOVES default fuel supply. The MOVES national average biodiesel ester volume default value, 3.4 percent over the entire period, however, was changed to reflect Texas-specific annual average values, based on EIA Texas state data for 2011 through 2019. The updated ester volumes used are shown in Table 22.

Table 22. Texas Annual Average Biodiesel Ester Volume Estimates

Year ID	Biodiesel Ester Volume[1]
2011	1.9%
2012	2.4%
2013	4.2%
2014	3.3%
2015	3.6%
2016	5.5%
2017	4.7%
2018	4.9%
2019 through 2060	4.3%

[1] Based on pertinent EIA fuel consumption data for Texas. 2011 was the first year with ester volumes above 1.0 percent. Non-ester conventional diesel formulations were assumed for years with biodiesel ester volumes less than 1.0 percent, i.e., 2010 and earlier.

4.2.5.5 Fuel Formulations

The updated MOVES default fuel formulation and supply input databases used in preparing the CDBs were provided in the electronic data submittal in Appendix B.

4.2.6 I/M Program Inputs

To model a local I/M program design, it must be defined using MOVES I/M coverage parameters by source type, and entered in the MOVES imcoverage table. The appropriate internal MOVES I/M factors for modeling a local I/M program are designated in a model run by the local program input data in the imcoverage table.[19]

MOVES adjusts emissions (Hydrocarbons [HC], CO, and NO_x) at the source-type level to incorporate the benefits of the local I/M program design defined using the MOVES imcoverage table parameters. TTI previously produced a comprehensive set of MOVES imcoverage records for Texas I/M counties to use in place of MOVES defaults. An I/M program is required in 17 Texas counties of the Austin, DFW, El Paso, and Houston areas (see Table 23 for a list of the counties).

TTI produced the local I/M coverage input parameters to represent Texas I/M program designs as specified in the Texas I/M 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), I/M area, and analysis year, current vehicle emissions testing may use On-Board Diagnostics (OBD) tests, the Acceleration Simulation Mode (ASM-2) test, or the Two-Speed Idle test.

Table 23 and associated notes describe MOVES imcoverage records developed by TTI for the years available in MOVES applicable to all 17 Texas I/M counties, with program start dates provided in the table notes. For additional I/M program details, see the current I/M SIP and/or pertinent Texas Administrative Code.[20]

[19] In general, MOVES produces a local I/M program effect as an adjustment to the model's internal reference I/M program effect (i.e., represented as the "standard I/M difference" in the pair of MOVES emissions rates [I/M – No I/M], which are specific to vehicle regulatory class categories of which the 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 to reflect the effects of various local I/M program design alternatives.

[20] Revision to the State Implementation Plan Mobile Source Strategies, Inspection and Maintenance State Implementation Plan Revision, TCEQ, adopted February 12, 2014.

Table 23. MOVES I/M Coverage Inputs for Texas Annual Inspections of Gasoline Vehicles, All Affected Counties/Years.

<table>
<tr><th>YearID[1]</th><th>begModel YearID[2]</th><th>endModel YearID[2]</th><th>testStandardsID[3]</th><th>Sourcetypeid[4]</th></tr>
<tr><td colspan="4">Dallas, Tarrant, El Paso</td><td rowspan="21">21
(PC – Passenger Car)

31
(PT – Passenger Truck)

32
(LCT – Light Commercial Truck)</td></tr>
<tr><td>1990</td><td>1975</td><td>1990</td><td>11 (Unloaded Idle)</td></tr>
<tr><td colspan="4">Harris, Dallas, Tarrant, El Paso</td></tr>
<tr><td rowspan="2">1999 through 2001</td><td>X</td><td>Y</td><td>12 (2500 RPM/Idle)</td></tr>
<tr><td>X</td><td>Y</td><td>41 (Evp Cap)</td></tr>
<tr><td colspan="4">El Paso</td></tr>
<tr><td rowspan="2">2002 through 2006</td><td>X</td><td>Y</td><td>12 (2500 RPM/Idle)</td></tr>
<tr><td>X</td><td>Y</td><td>41 (Evp Cap)</td></tr>
<tr><td colspan="4">1) Harris, Dallas, Tarrant, Collin, Denton
2) Brazoria, Fort Bend, Galveston, Montgomery, Ellis, Johnson, Kaufman, Parker, Rockwall</td></tr>
<tr><td rowspan="4">1) 2002 through 2019
2) 2003 through 2019</td><td>X</td><td>1995</td><td>23 (A2525/5015 Phase)</td></tr>
<tr><td>X</td><td>1995</td><td>41 (Evp Cap)</td></tr>
<tr><td>1996</td><td>Y</td><td>51 (Exh OBD)</td></tr>
<tr><td>1996</td><td>Y</td><td>45 (Evp Cap, OBD)</td></tr>
<tr><td colspan="4">1) Travis, Williamson; 2) El Paso</td></tr>
<tr><td rowspan="4">1) 2006 through 2019
2) 2007 through 2019</td><td>X</td><td>1995</td><td>12 (2500 RPM/Idle)</td></tr>
<tr><td>X</td><td>1995</td><td>41 (Evp Cap)</td></tr>
<tr><td>1996</td><td>Y</td><td>51 (Exh OBD)</td></tr>
<tr><td>1996</td><td>Y</td><td>45 (Evp Cap, OBD)</td></tr>
<tr><td colspan="4">All 17 I/M Counties[1]</td></tr>
<tr><td rowspan="2">2020 through 2060</td><td>X</td><td>Y</td><td>51 (Exh OBD)</td></tr>
<tr><td>X</td><td>Y</td><td>45 (Evp Cap, OBD)</td></tr>
</table>

[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; Travis, Williamson- 9/2005.
[2] begmodelyearID (X) and endmodelyearID (Y) define the range of model years covered –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] TCEQ provided updated source type compliance factor field input values (March 2021) for 2011, 2017, 2018, and 2019 calculated per Section 4.9.6, *MOVES Technical Guidance*, EPA, November 2020. TTI interpolated values for years between 2011 and 2017, used 2011 factor values for earlier years, and 2019 (latest available) values for future years. E.G., I/M county MOVES compliance factors by I/M area for 2019 and later, in percent:

DFW:	PC – 94.00;	PT – 90.35;	LCT – 70.74.
HGB:	PC – 95.00;	PT – 91.31;	LCT – 71.49.
AUS:	PC – 94.49;	PT – 90.83;	LCT – 71.12.
ELP:	PC – 94.50;	PT – 90.83;	LCT – 71.12.

Following is the general approach used to build the Texas imcoverage table:

- Identified MOVES I/M test standards applicable to Texas I/M counties in consultation with TCEQ (see Table 23, column 4).
- Queried MOVES database to determine the extent to which MOVES provides I/M effects corresponding to Texas I/M programs (i.e., test frequency, fuel type, and test types). From the result, TTI 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).
- Categorized counties and years in groups under pertinent MOVES test standards.
- Assigned MOVES I/M Program IDs such that: 1) all MOVES default I/M program IDs were excluded; and 2) for each year ID, each I/M program ID represented a unique combination of test standard, frequency, begin model year, and end model year.

4.2.7 Miscellaneous Other Inputs

Other tables included in the CDBs were two empty tables and two additional tables populated with defaults. These are:

- auditlog (includes a flag indicating whether an I/M program is required for the county)
- totalidlefraction (total idle fractions by month, for each county type, day type, idle region, and source type)
- countyyear (empty)
- hotellingagefraction (empty).

MySQL scripts were written to access the prepared input data (i.e., from databases or text files) and load the data into the 16,002 CDBs product. Basic QA checks including range of values, sum by categories, null values, were performed before preparing the final CDBs.

5 ESTIMATION OF EMISSION FACTORS

This section describes the development of the pollutant emission rates needed to calculate the summer weekday and annual on-road mobile source EIs for each Texas county and analysis year, using EPA's MOVES model (version 3.0.3).

Since 32,004 EIs were required, the emission rate development process was designed to minimize the MOVES runs needed. The emission rates development process was designed to produce both the summer weekday and annual emission rates using output from one set of MOVES county scale inventory mode runs. The MOVES run specifications were set to produce activity and emissions totals output by "portion of week" (i.e., the typical 2-day weekend and the typical 5-day work week) for each month of the year, by source type, fuel type, pollutant, emissions process, and road type. This type of aggregate output allowed calculation of emission rates for both summer weekday and annual periods, using the period aggregations of output from the one set of MOVES runs. These MOVES set-ups are highly suited to this trends emissions inventory application, due to the MOVES model run-time involved, and the number of inventories required. Emission rates were calculated by first expanding activity and emissions output for each portion of week to the weekday and weekend day portions of each month, then aggregating activity and emissions within each period (summer weekday and annual), and finally by dividing period total emissions by period total activity. To further reduce the total run-time required, representative counties were selected for each of up to 36 to 44 county groups, comprising all of Texas. The final rates for the representative counties were used in the EI calculations for each of their respective counties.

MOVES modeling parameters used were a combination of local and default inputs selected for suitability with this aggregate emission trends estimation methodology. The main reference for details on MOVES inputs for county scale modeling runs is EPA's *Technical Guidance*[21] for on-road emissions inventory development using MOVES3.

The following sections describe the emission rates development process including an overview, MOVES run specifications, inventory mode runs and checks, and post-processing.

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[21] EPA. 2020. *MOVES3 Technical Guidance: Using MOVES to Prepare Emission Inventories for State Implementation Plans and Transportation Conformity*, EPA-420-B-20-052, Office of Transportation and Air Quality. November 2020.

5.1 Overview

MOVES county scale inventory mode runs were developed to produce MOVES output databases by county and year containing emissions and activity data. Data contained in each MOVES output database were then post-processed into the final on-road emission rates used in the calculation of each summer weekday and annual EI.

The 254 Texas counties and 63 years in MOVES equated to a total of 16,002 MOVES model runs. TTI prepared all 16,002 MOVES inventory mode CDBs and county-scale MRS files as part of the deliverables in Task 3. In each analysis year, 254 Texas counties have been grouped into up to 36 to 44 county groups based on local fuel characteristics. In each county group, one representative county was selected to perform the "Portion of Week" inventory mode MOVES runs. All counties in the same county group shared the same emission rates post-processed from the representative county MOVES run[22]. With the grouping method, a total of 2,749 MOVES "Portion of Week" inventory mode runs were conducted using representative county CDBs containing the local input data (from the weekday/weekend EI activity data and various conversion factors) and some MOVES default input data. Each MOVES run required three main inputs: the MOVES3.0.3 database (movesdb20220105), a county-scale MRS file (by county and year), and a MOVES CDB containing the various local inputs (by county and year). The MOVES database was provided with the MOVES model, but the MRSs and CDBs were locally developed. The main work in setting up the modeling runs was processing the various local input data sets for populating the CDBs with local inputs (e.g., for fuels, meteorological, fleet characteristics, on- and off-network activity, control programs), in combination with MOVES defaults as appropriate (CDBs development was described previously in Section 4). Various tools were used in producing the inputs, such as MySQL, Python, and Microsoft Exel. Once the MRSs and CDBs were finalized, MOVES was run in batches, on multiple computers, over several months, to produce the necessary output.

Post-processing MOVES output databases to produce the emission rates was performed using Python scripts designed specifically for this application. Post-processing produced the activity-based emission rates in units defined by the on- and off-network activity as detailed in the previous sections (e.g., emissions per mile for

[22] Grouping method helped to significantly reduce the total time for MOVES run from 64,008 total hours (2 hours per run per scenario) to 5,498 hours (2 hours per run) while not losing resolution on emission rates with local fuel parameters.

VMT, emissions per start for vehicle starts, etc.). Post-processing was also performed to incorporate the effects of control programs not available in MOVES (i.e., TxLED).

Table 24 defines the rates produced for the external inventory calculations relative to traffic activity measures.

Table 24. Emission Rates by MOVES Emissions Process and Activity Factor.

Emissions Process	Activity[1]	Emission Rates[2]
Running Exhaust	VMT	mass/mile (mass/mi)
Crankcase Running Exhaust	VMT	mass/mi
Brake Wear	VMT	mass/mi
Tire Wear	VMT	mass/mi
Start Exhaust	Starts	mass/start
Crankcase Start Exhaust	Starts	mass/start
Extended Idle Exhaust	SHEI	mass/hour
Crankcase Extended Idle Exhaust	SHEI	mass/hour
Auxiliary Power Exhaust	APU Hours	mass/hour
Running exhaust (1) – Road Type 1 off-network	ONI Hours, SHP	mass/hour
Evaporative Permeation Evaporative Fuel Vapor Venting Evaporative Fuel Leaks	VMT, SHP	mass/mi, mass/hour

[1] VMT, ONI hours, SHP, vehicle starts, and the SHEI and APU hours components of hotelling are the basic activity factors. SHEI and APU hours are for combination long-haul trucks only.

The following sections describe the development of the MRSs and CDBs, the MOVES runs, and the post-processing performed to produce the emission rates input for the EI calculations.

5.2 MOVES Run Specifications

The MOVES Run Specification (MRS) is a file (in XML format) that 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 created an MRS for one county and year using the MOVES graphical user interface (GUI), then converted the MRS to a template and used it to build all the required MRS files. Table 25 describes the MRS selections followed by sections briefly discussing the selections.

Table 25. MRS Selections by MOVES GUI Navigation Panel.

Navigation Panel	Detail Panel	Selection
Scale	Model; Domain/Scale; Calculation Type	On-Road; County; Inventory
Time Spans	Years – Months – Days – Hours	<***YEAR***>[1] - All Months - All Day Types - All Hours
Geographic Bounds	States; Counties; Selections	Texas - <***COUNTY***>;[1] <***TX COUNTY SELECTION***>
On-Road Vehicles[2]	SUT/Fuel Combinations: 1 – Gasoline, 2 – Diesel, 3 – CNG, 5 – E85 (85% ethanol-15% gasoline blend), 9 – Electric	<u>SUT</u> — <u>Fuel Types</u> Motorcycle: 1 - - - - Passenger Car: 1 2 - 5 9 Passenger Truck: 1 2 - 5 9 Light Commercial Truck: 1 2 - 5 9 Other Buses: 1 2 3 - - Transit Bus: 1 2 3 - - School Bus: 1 2 3 - - Refuse Truck: 1 2 3 - - Single Unit Short-Haul Truck: 1 2 3 - - Single Unit Long-Haul Truck: 1 2 3 - - Motor Home: 1 2 3 - - Combination Short-Haul Truck: 1 2 3 - - Combination Long-Haul Truck: - 2 - - -
Road Type	Selected Road Types	Off-Network – Rural Restricted Access – Rural Unrestricted Access – Urban Restricted Access – Urban Unrestricted Access
Pollutants[3] and Processes	VOC; CO; NO_X; SO_2; NH_3; CH_4; N_2O; Atmospheric CO_2; CO_2 Equivalent; $PM_{2.5}$: Total Exhaust, Brakewear, and Tirewear; PM_{10}: Total Exhaust, Brakewear, Tirewear; Benzene, Ethanol, 1,3-Butadiene; Formaldehyde; Acetaldehyde; Acrolein; Naphthalene	Dependent on pollutants: 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
General Output	Output Database; Units; Activity	<***MOVES OUTPUT DATABASE NAME***>;[1] Grams, Joules, Miles; Distance Travelled, Source Hours, Hotelling Hours, Source Hours Operating, Source Hours Parked, Population, Starts
Create Input Database	Domain Input Database	<***CDB NAME***>[1]
Output Emissions Detail	Output Aggregation; For All Vehicles/Equipment; On Road	Time: Portion of Week[4], Geographic: County; Fuel Type, Emission Process; Road Type, Source Use Type

[1] Limited to one county and year per county scale run.
[2] Although MOVES requires all fuel types to be included in MRSs, only gasoline and diesel were modeled per CDB inputs.
[3] Prerequisite pollutants that were needed to model the reported pollutants are not shown.
[4] With all months and day types selected, "Portion of Week" aggregates hourly results to output total emissions and activity over a 5-day work week portion and a typical 2-day weekend portion for each month of the calendar year.

5.2.1 Scale

The MOVES Domain/Scale "County" was selected for producing local, county output, with the limitation of one county and year per run. The MOVES Calculation Type "Inventory" was selected for MOVES to produce inventory activity and emissions output, for the specified county and year, needed for calculating (by post-processing) summer weekday and annual emission rates for the inventory estimation process.

5.2.2 Time Spans

The Time Spans parameters of all months, both day types, all hours, and one year were specified to produce internal activity and emissions results, for the year and county selected, needed for subsequent output aggregations by "Portion of Week" (as determined by selections in the Output Emissions Detail panel, discussed later).

5.2.3 Geographic Bounds

Per the MOVES County Scale limitation, only one county was selected per run. On-Road Vehicles and Road Type

The local VMT mixes developed for the study include the SUT/fuel type combinations modeled with MOVES, namely, gasoline and diesel vehicle types. The VMT mixes specify the vehicle fleet as the gasoline and diesel SUTs designated as "on-road vehicles" selections in Table 25. These SUT/fuel type combinations were selected in all the MRSs. All other SUT/fuel type combinations available in MOVES were also selected as required by MOVES to execute properly, but only gasoline and diesel were modeled. Fuel types output was controlled through adjustments to the MOVES default fuel engine fractions via the MOVES AVFT table and the flex-fuel vehicle fuel use information of the fuelusagefraction table of the CDBs. All five MOVES road-type categories were selected.

5.2.4 Pollutants and Processes

In addition to the pollutants defined by the scope of the inventory, MOVES requires that additional pollutants be selected for "chained" pollutants (i.e., pollutants that are calculated as a function of another MOVES pollutant). Chained pollutants were only reported if required. All of the associated on-road processes (excludes refueling processes) available for the selected pollutants were included.

5.2.5 General Output and Output Emissions Detail

In the General Output panel, output units of grams, joules, and miles were selected. All of the Activity output categories were selected, as these were needed for post-processing the inventory output to produce the emission rates:

- Distance Traveled.
- Source Hours.
- Hotelling Hours.
- Source Hours Operating.
- Source Hours Parked.
- Population.
- Starts.

In the Output Emissions Detail panel, aggregation selections were made as needed for the summer weekday and annual emission rates post-processing procedure, which included inventory output for each pollutant by:

- Source Use Type.
- Fuel Type.
- Emission Process.
- Road Type.

The output aggregation selection for temporal resolution was:

- Portion of Week (total emissions for a 5-day work week portion and a typical 2-day weekend portion for each month selected [i.e., all months]).

5.3 Quality Control

After completing the input data preparation, the CDBs, developed as described in Section 4, were checked to verify that all tables were in the appropriate CDBs and the tables were populated with data as intended. The MOVES RunSpecs were executed in batches using the MOVES commandline tool. After completion, TTI verified that the

MOVES runs were error-free (i.e., checked all run log text files for errors and warnings and compared record counts in each rate table between output databases).

5.4 County Group Emission Rates from MOVES Output

TTI processed the output activity and emissions quantity tables from the output database of each county group discussed in section 5.1. The county groups by analysis years (1990, 1999 – 2002, 2003 – 2005, and 2006 – 2060) are provided in Appendix H. The activity was obtained from the "movesactivityoutput" table, and emission quantities were obtained from the "movesoutput" table.

Activity output for a county group consisted of the activity categories listed in section 5.2. In addition, ONI was computed by filtering the "Source Hours Operating" for road type 1 (off-network) to get the off-network source hours operating, also known as ONI. The activity output table provided activity data for each source use type, fuel type, and road type for a typical 5-day work week portion and a typical 2-day weekend portion for each month of the analysis year. A month's net weekend or weekday activity can be obtained by multiplying the output activity portions for the typical week associated with weekdays or weekends by the number of weeks in that month, respectively.

Emission quantity for a pollutant for a county group was reported for each emission process, source use type, fuel type, and road type for a typical weekday and weekend for each month of the analysis year. The net weekend or weekday emission quantity of a month can be obtained by multiplying the emission quantity on a typical weekend or weekday by the number of weekends or weekdays in that month, respectively.

Each county group's activity and emission quantity tables were post-processed to produce the on-road mobile source emission rate tables for each pollutant and process by source use type, fuel type, and road type. The following post-processing procedures were performed.

1. The activity and emission quantities from the output database were converted to the summer weekday and annual activity.
    - The total summer weekday activity and emissions were calculated by scaling the activity and emission from typical weekdays from June, July, and August using the total number of weekdays in these months, respectively, and summing the results from the three months. This

converted the average weekday activity and emission quantity of the individual summer month to total summer weekday values.

- Annual activity and emissions rates were computed using the same methodology as summer weekday rates but using the data from all months, weekdays, and weekends instead of just the summer months and weekdays.

2. For summer weekday and annual analysis, emission quantity mapping described in Table 24 was used to join the activity with the emission quantity tables for the summer weekday and annual period obtained from the above step. After merging the emission and activity table, on-network and off-network emission rates in terms of mass per vehicle activity unit (i.e., mass/mile, mass/SHP, mass/start, mass/ONI hour, mass/SHEI, mass/APU hour) were obtained by dividing emissions by the corresponding activity. The summer weekday data provided average summer weekday rates, while the annual data provided annual average daily emission rates.
    - Total Gaseous Hydrocarbons, Benzene, Ethanol, Non-Methane Hydrocarbons, and Volatile Organic Compounds off-network emissions for gasoline-powered vehicles were computed using the mass/SHP factor as gasoline-powered vehicles emit these pollutants even when the engine is turned off. While for other pollutant and fuel type combinations, emissions were computed using the mass/ONI rates.
3. TxLED adjustments (see factors provided by TCEQ in Table 26) were applied to the diesel vehicle NO_X emission rates in all counties where TxLED applies. TCEQ produced these average diesel SUT NO_X adjustments using 4.8 percent and 6.2 percent reductions for 2002-and-later and 2001-and-earlier model years, respectively.[23, 24] TxLED factors were applied for the analysis year 2006 and onwards and were interpolated from adjacent years for the years not covered in the table below.

[23] Reductions as detailed in the EPA Office of Transportation and Air Quality Memorandum, RE: TxLED Fuel Benefits, September 27, 2001.

[24] The TxLED counties list may be found at: http://www.tceq.texas.gov/airquality/mobilesource/txled/txled-affected-counties. For full details on the TCEQ TxLED factor development procedure, see TxLED estimation spreadsheets at: ftp://amdaftp.tceq.texas.gov/pub/EI/onroad/txled/.

The post-processed rates were developed for each county group for each pollutant and process. The rates were created by source use type, fuel type, and road type. The following section describes the method used for applying these rates to the corresponding activity of each Texas county.

Table 26. TxLED Adjustment Factors Summary.

Source Use Type	Source Use Type ID	Year										
		2006	2011	2017	2018	2019	2020	2023	2024	2026	2027	2032+
Passenger Car	21	0.9360	0.9419	0.9491	0.9503	0.9506	0.9508	0.9514	0.9516	0.9517	0.9518	0.952
Passenger Truck	31	0.9407	0.943	0.9459	0.9464	0.947	0.9477	0.9489	0.9494	0.9498	0.9501	0.952
Light Commercial Truck	32	0.9409	0.943	0.9455	0.946	0.9466	0.9473	0.9485	0.949	0.9494	0.9496	0.952
Other Buses	41	0.9401	0.9423	0.945	0.9456	0.9461	0.9468	0.9481	0.9486	0.9494	0.9498	0.952
Transit Bus	42	0.9446	0.9467	0.9493	0.9496	0.9499	0.9502	0.9508	0.951	0.9512	0.9513	0.952
School Bus	43	0.9406	0.9433	0.9466	0.9471	0.9476	0.9481	0.9494	0.9497	0.9503	0.9506	0.952
Refuse Truck	51	0.9414	0.9436	0.9463	0.9468	0.9474	0.9479	0.9495	0.95	0.9508	0.9512	0.952
Single Unit Short-Haul Truck	52	0.9468	0.9486	0.9508	0.9510	0.9512	0.9514	0.9518	0.9519	0.9519	0.952	0.952
Single Unit Long-Haul Truck	53	0.9472	0.9489	0.9509	0.9510	0.9512	0.9513	0.9516	0.9517	0.9518	0.9518	0.952
Motor Home	54	0.9433	0.9439	0.9447	0.945	0.9453	0.9456	0.9467	0.9474	0.9483	0.9491	0.952
Combination Short-Haul Truck	61	0.9428	0.9461	0.95	0.9502	0.9503	0.9506	0.9513	0.9515	0.9517	0.9518	0.952
Combination Long-Haul Truck	62	0.9412	0.9444	0.9482	0.9485	0.9488	0.9492	0.9507	0.951	0.9514	0.9516	0.952

Source: TCEQ, March 2021. The TCEQ procedure used MOVES3 and the latest available data (i.e., statewide age distributions and local AVFT inputs based on year-end 2018 TxDMV vehicle registration data).

6 EMISSIONS CALCULATIONS

The following sections describe the details of the summer weekday and the annual emission inventory calculations by county for each analysis year.

6.1 Summer Weekday Emissions Calculations

The summer weekday emission calculation uses the following quantities:

- County-level 24-hour summer weekday MOVES road type and SUT/fuel type VMT;
- County-level hourly SUT/fuel type 24-hour summer weekday off-network activity estimates (SHP, starts, ONI, SHEI, and APU hours); and
- 24-hour summer weekday MOVES-based aggregate emissions factors for each county corresponding to the analysis county. These factors are by pollutant, process, SUT, fuel type, MOVES road type, and activity type, which includes both the VMT-based ("on-network") and off-network emissions factors.
- TTI calculated the summer weekday emissions by county for each analysis year using the Emission Calculation Utilities (see utility descriptions in Appendix C). Whereas typical emissions inventories use a link-based method, the summer weekday emissions were calculated using an aggregate, MOVES "rates-per-activity" emissions modeling approach as described in Section 5. For each combination of pollutantID, processID, sourceTypeID, fuelTypeID, and roadTypeID, the aggregate emissions calculations fall into two categories: VMT-based emissions calculations and off-network emissions calculations. The VMT-based emissions calculations use the 24-hour MOVES road type and SUT/fuel type VMT to estimate emissions at the MOVES road type and SUT/fuel type level. The off-network emissions calculations use the 24-hour off-network activity (ONI, SHP, starts, SHEI, and APU hours by SUT/fuel type) to estimate emissions at the county level by SUT/fuel type. The emissions were calculated by multiplying the emissions factors by the appropriate activity.
- Two output files were produced by the calculation: a tab-delimited 24-hour emissions output file (lists activity by county, year, MOVES road type, and SUT/fuel type and emissions by county, year, MOVES road type, pollutant,

pollutant process, and SUT/fuel type), and a tab-delimited 24-hour emissions summary by SCC[25] output file.

- TTI converted the 24-hour summer weekday emissions and activity results for each year to a format compatible for uploading to TCEQ's Texas Air Emissions Repository (TexAER) based on EPA's Emissions Inventory System (EIS) NEI CERS XML format in Appendix K.

6.2 Annual Emissions Calculations

The annual emission calculation uses the following quantities:

- County-level annual MOVES road type and SUT/fuel type VMT;
- County-level annual off-network activity estimates (SHP, starts, ONI, SHEI, and APU hours); and
- Annual average daily MOVES-based aggregate emissions factors for each county corresponding to the analysis county. These factors are by pollutant, process, SUT, fuel type, MOVES road type, and activity type, which includes both the VMT-based ("on-network") and off-network emissions factors.

TTI calculated the annual emissions by county for each analysis year using the Emission Calculation Utilities (see utility descriptions in Appendix C). Whereas typical emissions inventories use a link-based method, the annual emissions were calculated using an aggregate, MOVES "rates-per-activity" emissions modeling approach as described in Section 5. For each combination of pollutantID, processID, sourceTypeID, fuelTypeID, and roadTypeID, the aggregate emissions calculations fall into two categories: VMT-based emissions calculations and off-network emissions calculations. The VMT-based emissions calculations use the annual MOVES road type and SUT/fuel type VMT to estimate emissions at the MOVES road type and SUT/fuel type level. The off-network emissions calculations use the annual off-network activity (ONI, SHP, starts, SHEI, and APU hours by SUT/fuel type) to estimate emissions at the county level

[25] The SCCs are 10 digits, composed of "22" (code for on-road mobile source) followed respectively by the four, two digit MOVES category IDs: fuelTypeID, sourceTypeID, roadTypeID, and processID. Thus, all these dimensions were retained in the XML inventory summary.

by SUT/fuel type. The emissions were calculated by multiplying the emissions factors by the appropriate activity.

Two output files were produced by the calculation: a tab-delimited annual emissions output file (lists activity by county, year, MOVES road type, and SUT/fuel type and emissions by county, year, MOVES road type, pollutant, pollutant process, and SUT/fuel type), and a tab-delimited annual emissions summary by SCC output file.

TTI converted the annual emissions and activity results for each county to a format compatible for uploading to the TCEQ's TexAER based on the EPA's EIS NEI CERS XML format, which uses EPA's EIS inventory data codes, using the same procedures as the conversion of the summer weekday 24-hour emissions and activity.

7 QUALITY ASSURANCE

Analyses and results were subjected to appropriate internal review and QA/QC procedures, including independent verification and reasonableness checks. All work was completed consistent with applicable elements of American Society for Quality, American National Standard Institute (ASQ/ANSI): E4: 2014: *Quality Management Systems for Environmental Information and Technology Programs – Requirements with Guidance for Use*, February 2014, and the TCEQ Quality Management Plan.

The Quality Assurance Project Plans (QAPP) category and project type most closely matching the intended use of this analysis are QAPP Category III for Data Evaluation or Use for Secondary Purpose purpose[26]. Internal review and quality control measures consistent with the QA category and project type-specific requirements provided in Guidance for Quality Assurance Project Plans for Modeling, EPA QA/G-5M,[27] along with appropriate audits or assessments of data and reporting of findings, were employed. These include but are not limited to the elements outlined, per EPA Requirements for Quality Assurance Project Plans (EPA QA/R-5),[28] in the following description.

7.1 Project Management

The definition and background of the problem addressed by this project, the project/task description, and project documents and records are as described in the Purpose and Background sections of the GAD. No special training or certification was required. The TTI project manager ensured project personnel used the most current, approved version of the QAPP.

The objective was to produce emissions inventories of the quality level required for air quality modeling, according to the guidance and methods documents as referenced, and in consultation with the TCEQ project manager.

TTI used basic criteria to assure the acceptable quality of the product. TTI assured the acceptable quality of the product by verifying that the process and product were as stated in the GAD and in the final deliverable products. This included verifying:

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[26] PDF available at: QAPP REQUIREMENTS FOR PROJECTS USING SECONDARY DATA (archive-it.org)

[27] PDF available at: https://www.epa.gov/sites/production/files/2015-06/documents/g5m-final.pdf.

[28] PDF available at: https://www.epa.gov/sites/production/files/2016-06/documents/r5-final_0.pdf.

- The product met the purpose of the trend emissions inventory development (i.e., needed for CAPs, CAP precursors, GHGs, and HAPs to support air quality planning activity);
- The full extent of the analysis domain was included (i.e., analysis year, geographic coverage, seasonal periods, days, sources, etc.);
- Agreed methods, models, tools, and data were used as specified in the QAPP;
- Procedures, tools used, and all required emissions output datasets (inventory summary files and CERS XML Files) were produced as specified in QAPP

7.2 Measurement and Data Acquisition

Note that no sampling of data was involved in the emissions inventory development; thus, only existing data (non-direct measurements) were used for this project.

The data needed for project implementation was for the development of emission rate and emissions inventory model inputs and adjustment factors and the development of the activity inputs for both internal (relatively aggregate) and external (detailed, link-level) emissions calculations. Existing data acquired from various organizations (e.g., TxDOT, Metropolitan Planning Organization (MPO), Council of Governments (COG), TCEQ, and/or the EPA, and in most cases have been QA'd by the providing agency) was reviewed by TTI for suitability, and in most cases was previously QA'd by the providing agency. These data sets included: HPMS data (from TxDOT's RIFCREC report); speed model data; vehicle registration data; ATR data; vehicle classification count data; meteorological data; fuels data; MOVES emissions model data; extended idling activity data; and vehicle I/M program design data.

Any significant problems found during review, verification, and/or validation were corrected, and the QA procedure was repeated until satisfied. No significant problems were found during QA.

7.3 Data Management

The assigned staff on the TTI team used the same electronic project folder structure on their workstations. As various scripts, inputs, and outputs were developed in the assessment process, data was shared within the team for crosschecking via an intranet, flash drive, or external hard drive. After data were QA'd, depending on the size of the data set, the data sets were backed up and stored in compressed files along with the

QA record/s. These activities were performed throughout the process until the final products are produced.

For MOVES model runs to produce emissions factor look-up tables for the emissions inventories, all run files (MOVES model inputs and batch files) were produced on an individual workstation. After the MOVES input data and batch files (i.e., Run Files) had been QA'd, they were either executed on an individual workstation, or they were copied (via external hard drive) to the MOVES modeling cluster's master computer and executed. Upon execution, completion, and error checking, the MOVES output databases and run log text files were (for cluster runs first copied to an individual workstation) archived and processed further in preparation for input to the emissions calculations utility.

After the final product was completed, all project data archives were compiled on an external drive for very large project data sets. TTI kept a complete archive of the project data (EI development scripts used in the process were included). An electronic data submittal package was produced along with a data description for delivery to TCEQ (on the external hard drive).

7.4 Assessment and Oversight

The following assessments were performed:

- **Completeness** – TTI ensured that data gathered were checked to address completeness. As part of this quality control process, TTI verified that data sets were within the required dimensions and all required fields were populated and properly coded or labeled.
- **Representativeness** – TTI ensured that data gathered were checked to address representativeness. TTI ensured that MOVES3 inventory mode CDB inputs were assessed to represent local activity and conditions. However, where local data were unavailable, steps were taken to use MOVES default data.
- **Comparability** – MOVES3 emissions and activity data were compared to the most recent work of prior studies and where applicable to other MOVES emissions inventories. TTI analyzed any significant difference if the reason for the difference was not obvious.

In the case of any inconsistency or deficiency found, the issue was directly communicated to responsible staff for correction (or outside agency staff involved, if any). After any correction, QA checks were repeated to assure the additional work resulted in the intended result, and were noted in the QA record.

Any major problems were reported to the project manager and communicated to the project team as needed, as well as when various data elements passed QA checks and were ready for next steps. The project manager ensured all of the QA checks performed were compiled and maintained in the project archives.

In addition, technical systems audits were performed. Audits of data quality at the requisite 10 percent level were performed for any data produced as part of this study. QA findings were reported in both the draft and the final reports.

7.5 Data Validation

Erroneous or improper inputs at any point during the emissions inventory development process may produce inaccurate emissions estimates. The TTI project team performed QA checks at each step of the analysis to ensure data quality.

The criteria for passing quality checks were summarized in the following. These QA guidelines were used to ensure the development of emissions inventories that were as accurate as possible and met the requirements of TCEQ's intended use.

As previously stated, TTI verified the overall scope of the emissions analysis to include:

- Purpose (i.e., needed for developing trends emissions inventories).
- Modeling domain (e.g., analysis years, geographic coverage, seasonal periods, days, sources, pollutants).
- Methods, models, and data (e.g., default versus local input data sources).
- Procedures, tools, and required emissions output data sets.

TTI performed checks on input data, model execution, and output, as follows:

- Input data preparation:
    - The basis of input data sets as planned (e.g., actual, historical, latest available, validated model) and aggregation levels.
    - Depending on the procedure and input data set, verification of calculations.

    - Use of correct data dimensions, fields, coding, labeling, formats; distributions sum to 1.0 where appropriate.

- Reasonability checks: (discussed in the next section).
    - External data sources quality assurance verification.
- Model or utility execution:
    - Correct number of utility or model run input files per application.
    - Utility control or model run specifications verification (e.g., per applicable user guide, correct inputs, output options).
- Output:
    - Correct output files by type and quantity.
    - Expected output file sizes.
    - Warnings and errors (e.g., checks of any written to output run logs).
    - Required data, proper coding/labeling, formats.
    - Assessment of any unusual results.

TTI performed further checks for consistency, completeness, and reasonability of data output from model or utility applications.

- Any activity, emission rate, or emissions adjustments were performed as intended.
- Noted whether directional differences were as expected (e.g., between scenarios with temporal or geographic variation).
- Checked for consistency (e.g., input data control totals versus output summaries, utility raw results versus post-processed results).
- Comparisons of results to results from previous similar analyses, where available.

Any additional data products required for the emissions analysis were subjected to the appropriate QA checks previously listed. Any issues found needing resolution were corrected, and appropriate QA checks were performed until satisfied, ensuring the project results met the TCEQ requirements, i.e., as outlined in the GAD and QAPP.

8 FINDINGS AND RECOMMENDATIONS

This section covers the findings of this project.

8.1 Summer Weekday Findings

The following sections discuss the findings TTI made on the summer weekday emissions for both on-network and off-network activity. The summer weekday on-network and off-network mobile source emissions are available in Appendix J.

8.1.1 On-network Findings

Overall, TTI observed a consistent decrease in summer weekday emissions for most of the major pollutant species, including VOC, CO, and $PM_{2.5}$, between 1990 and 2060. SO_2 emissions, while decreasing consistently between 1990 and 2060, had an unusual trend that was not seen in other pollutant species. TTI suspects the increased penetration of gasoline direct injection engines and SO_2 start rates in MOVES3 following the sulfur content trends in the fuel formulation to be a potential cause for the fluctuating SO_2 emissions before 2020.

NO_x and N_2O summer weekday on-road emissions increased from 1990 to 2000, and then followed a consistent decline until 2060 at all counties within the state. In their *Air Toxic Emissions from Onroad Vehicles in MOVES3* report, the EPA noted that light-duty gasoline vehicles regulated under the National Low Emission Vehicle program started with vehicles with "model year 2001 and later", which was likely the cause of different trends in NO_x and N_2O between 1990 and 2000 compared to post-2000.

While PM_{10} emissions in 2060 were lower than in 1990, TTI observed a slight upward trend for summer weekday on-road PM_{10} emissions starting in 2020. CO_2 and NH_3 summer weekday on-road emissions saw increased emissions since 1990. In their *Overview of EPA's Motor Vehicle Emission Simulator (MOVES3)* report, the EPA noted that MOVES3 accounts for the less stringent, March 2020 Safer Affordable Fuel Efficient (SAFE) Vehicles standards for light-duty cars and trucks, which increased fuel consumption and CO_2 emissions. More investigation is required for upward tick of PM_{10} starting in 2020 and NH3 emissions.

8.1.2 Off-Network Findings

Overall, the summer weekday off-network activity had very similar trends to their on-network counterparts, and thus, the discussion made previously should apply as well.

The off-network PM_{10} and $PM_{2.5}$ emissions were the only pollutants to have significantly different trends compared to their on-network counterparts, also the $PM_{2.5}$ trend here is consistent with the PM_{10} trends (for on-network emissions, PM_{10} emissions started to increase towards 2060, whereas $PM_{2.5}$ emissions consistently decreased). Both PM trends saw an increase prior to 2007. Also, as discussed in their *Brake and Tire Wear Emissions from Onroad Vehicles in MOVES3* report, the EPA noted that MOVES does not model off-network idle or extended idle emissions for tire wear because the vehicle is completely stopped during this nondrive-cycle idle time.

8.2 Annual Findings

This section discusses TTI findings for both the on-network and off-network activity in the annual period across all Texas Metropolitan Planning Areas.

The annual on-road mobile source emissions are available in Appendix I.

8.2.1 On-Network Activity

Similar to the summer weekday period, the emissions for VOC, CO, NO_x, SO_2, and $PM_{2.5}$ had consistently declined since 1990. PM_{10}, CO_2, and NH_3 emissions did not see consistent decreasing trends like the other species. In their *Overview of EPA's Motor Vehicle Emission Simulator (MOVES3)* report, the EPA noted increased fuel consumption and CO_2 emissions due to the less stringent, March 2020 SAFE Vehicles standards for light-duty cars and trucks.

8.2.2 Off-Network Activity

Overall, the annual off-network activity had very similar trends to their on-network counterparts, and thus, the discussion made previously should apply as well.

8.3 Recommendations

TTI believes that the trend inventory can be improved by incorporating detailed activity and speed estimates on individual roadway links acquired from the state agencies and MPO roadway networks. Such continued improvements are important, as the results of the trends emissions inventories have been extensively used by air quality and transportation planners in long and short-range planning activities over the years. Such improvements may add significant value to these stakeholders.

Data such as VMT, speeds, vehicle population, growth factors, VMT mix, I/M factors, fuel parameters, etc. used in trend emissions inventory change regularly. In addition, EPA's emissions model and assumption change as new updates/patches are implemented and release version changes. So, TTI recommends continuing to develop trend inventories every 3 to 5 years so that updated activity, population, and growth factors may be applied in the emissions development at these intervals and the emissions trends will not become too outdated.

The above findings on emissions trends for different pollutants in the future and the reasoning for these changes over time are from a preliminary exploratory analysis. TTI recommends a detailed analysis of the trend data corroborating it with EPA's technical documentation would be beneficial for the user community.

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APPENDIX A.1: MOVES3 254 COUNTY ON-ROAD ANNUAL TRENDS EI CDB FROM 1990 TO 2060 (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the finalized MOVES3 inventory mode CDB which were used to generate annual emission rates. It is part of task 3 deliverable of this project.

APPENDIX A.2: MOVES3 254 COUNTY ON-ROAD ANNUAL TRENDS EI CDB FROM 1990 TO 2060 (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the finalized MOVES3 inventory mode CDB which were used to generate summer weekday emission rates. It is part of task 3 deliverable of this project.

APPENDIX B: MOVES3 ON-ROAD TRENDS EI CDB INPUT DATABASE AND FILES (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains input data files such as fuel parameters, control programs, fleet characteristics, meteorology, etc. used in the development of MOVES3 inventory mode CDB povided in Appendix A.1 and A.2. It is part of task 3 deliverable of this project.

APPENDIX C: EMISSIONS UTILITIES FOR MOVES-BASED EMISSIONS INVENTORIES (ELECTRONIC ONLY)

TTI Emissions Estimation Utility Modules for 24-Hour Aggregate MOVES-Based Emissions Inventories

The following is a summary of the utilities developed by TTI (written in the Python programming language) for producing 24-hour aggregate emissions estimates for on-road mobile sources using the latest version of EPA's MOVES3 model. These utilities produce inputs used with the MOVES model, calculate the necessary activity (VMT and off-network activity), calculate 24-hour emission factors, make special adjustments to the emissions factors (when required), and multiply the emissions factors by the activity estimates to produce the 24-hour aggregate emissions.

The main utilities for calculation the 24-hour aggregate emissions using MOVES are same as what have been used in most recent TCEQ emission inventory projects (AERR, RFP, etc.) including HPMS based link based VMT calculation module, vehicle population calculation module, off-network activity calculation module. New utilities have been added to build MOVES CDB Activity Inputs, summarize hourly activity to 24-hour aggregate activity and emissions, to adjust "rate-per-activity" emission rates and calculate 24-hour aggregate emissions for both summer weekday and annual scenario:

- HPMS based Link VMT Module
- Vehicle Population Module
- Offnetwork Activity Calculation Module
- MOVES CDB Activity Input Build Module
- 24-Hour VMT Summarization Module
- 24-Hour Rates Adjustment Module
- Emissions Calculation Module

HPMS Based Link VMT Module

The HPMS based Link VMT calculation module processes analysis scenario (by year, season, day type) county level VMT control totals to produce analysis scenario county level hourly VMT by MOVES road type and SUT/FT. The main inputs to this module:

- County-level, 24-hour analysis scenario VMT control totals;
- County HPMS data sets, which include AADT VMT, centerline miles, and lane miles by HPMS area type and functional class;
- Hourly VMT distributions;
- 24-hour or time period VMT mix by roadway type, MOVES source type, and MOVES fuel type;
- Time period designations (only if time period VMT mix is used); and
- HPMS roadway type designations, which list associations of the link roadway types/area type combination to the VMT mix, emissions rate, and MOVES roadway types.

The utility module initially calculates the HPMS functional class/area type VMT distribution from the county HPMS data sets by dividing the HPMS functional class/area type AADT VMT by the county total HPMS AADT VMT. The county-level, 24-hour analysis scenario VMT is then distributed to each HPMS functional class/area type by multiplying this distribution by the county-level, 24-hour VMT control total. The 24-hour HPMS functional class/area type VMT is then distributed to each hour of the day using the hourly VMT distribution.

The utility module then distributes the hourly HPMS functional class/area type VMT to each SUT/fuel type using the VMT mix and the HPMS roadway type designations. For each HPMS functional class/area type, the appropriate VMT mix road type is selected from the HPMS roadway type designations and the VMT mix for that VMT mix road type is applied to the hourly HPMS functional/area type VMT. If the 24-hour VMT mix is used, each hour uses the same VMT mix data set. If the time period VMT mix is used, each hour is assigned a time period based on the time period designations and the appropriate time period VMT mix data set is used.

The utility module then calculates the hourly VMT by MOVES road type and SUT/fuel type. For each hour, the HPMS functional class/area type combinations are assigned a MOVES road type using the HPMS roadway type designations and the hourly VMT is aggregated across MOVES road types to produce the county-level hourly VMT by MOVES road type and SUT/fuel type.

Vehicle Population Build Module

The Vehicle Population Build utility module builds the sourcetypeyear data files in a format consistent with the MOVES input database table and the SUT/fuel type population input file to estimate emissions or the offnetwork activity module 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 Passenger Vehicle, Motorcycles, Trucks <=6000, Trucks >6000 <=8500, Total Trucks <=8500, Gas Trucks >8500, Diesel Trucks >8500, TotalTrucks >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;
- No roadtype 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; and
- Population scaling factor file (optional);

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 20.

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:

- SUT 11 to Registration Category 2,
- SUT 21 to Registration Category 1,
- SUT 31 and 32 to Registration Category 3,
- SUT 41, 42, 43, 51, 52, 54 to Registration Category 4 and 6,
- SUT 61 to Registration Category 5 and 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, each fuel type VMT mix fraction is divided by the total VMT mix for SUT 21. For SUT 31, each fuel type VMT mix fraction is divided by the total VMT mix for SUTs 31 and 32. The same process applies to SUT 32. For SUT 41, each fuel type VMT mix fraction 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, each fuel type VMT mix fraction is divided by the total VMT mix for SUT 61.

For SUT 11, the SUT population factor for fuel type 1 (gasoline) is set to 1 with all other factors set to 0. For SUT 53, the SUT population factors by fuel type are calculated by dividing each fuel type VMT mix fraction 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 each fuel type VMT mix fraction 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 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.

Offnetwork Activity Calculation Module

The Off-network activity utility module calculates the analysis scenario off-network activity (ONI, Adjusted SHP, starts, SHEI and APU hours activity) by hour and SUT/fuel type (SHEI and APU hours activity are for SUT 62, fuel type 2 [CLhT_Diesel] only).

The ONI is calculated for each hour of the day using the following formula:

$$\text{ONI Hours} = (\text{SHOnetwork} * \text{TIF} - \text{SHI}_{network}) / (1 - \text{TIF}).$$

Where:

$SHO_{network}$ = the SHO on each link. This is calculated by dividing the VMT associated with each link by the link's congested speed.

$SHI_{network}$ = the total SHI that occurs on the network (idling that occurs as a component of drive cycles) and is calculated by multiplying $SHO_{network}$ by a RIF. RIF is the proportion of idling (in units of time) that occurs within a drive-cycle at a specified operational speed. Default values for RIF are used as defined in the MOVES data table *roadidlefraction*.

TIF = the total idle fraction, i.e., the ratio of total source hours idling and total source hours operating. Default values for TIF are used as defined in the MOVES database table *totalidlefraction* (three-month seasonal averages for summer weekday scenario and 12-month averages for the annual scenario).

The Adjusted SHP is calculated using hourly MOVES road type and SUT/fuel type VMT, an average speed distribution (same format as the MOVES default average speed distribution), and the SUT/fuel type population, and ONI activity. To calculate the Adjusted SHP activity, the utility first calculates the hourly MOVES road type and SUT average speed by applying the average speed distribution to the average speed bin speeds from MOVES and summing across the average speed bins. The utility then calculates the VHT (or SHO) by SUT/fuel type by dividing the hourly MOVES road type and SUT/fuel type VMT by the hourly MOVES road type and SUT average speed and aggregating across the MOVES road types; thus producing hourly SUT/fuel type SHO. The hourly SUT/fuel type SHP is calculated by subtracting the hourly SUT/fuel type SHO from the hourly SUT/fuel type total hours(since these are hourly calculations, total hours are set equal to the vehicle population). If the calculated SHP is negative (i.e., SHO is greater than the total hours), the SHP is set to 0. Adjusted SHP was then calculated by subtracting ONI hours from the previously calculated SHP.

Vehicle starts are estimated using county-level vehicle type populations and data from MOVES representing the average number of vehicle starts per vehicle type per hour. The starts per vehicle are calculated using the applicable MOVES algorithm with data on the age distribution and fuel fractions of the local fleet[29]. Local age distributions and fuelfractions inputs to MOVES are combined with MOVES default parameters (startsageadjustment, startsmonthadjust [three-month seasonal average for summer weekday scenario and 12-month average for annual scenario], and startspervehicle) to produce 24-hour starts per vehicle output representative of each seasonal period. The MOVES output provides the scenario-specific starts per vehicle defined by the study scope. For each hour of the day, the starts per vehicle data calculated by the MOVES algorithm are multiplied by the local vehicle type population estimates to produce the total number of starts by vehicle type per hour.

The SHEI and APU hours activity are a function of hotelling hours and are calculated using base data (24-hour hoteling and hourly MOVES road type and SUT/fuel type VMT), the analysis scenario data used to calculate the SHP, and the analysis scenario SHP. The utility also aggregates the SHP across hours to produce the daily SUT/fuel Type SHP. The utility module first calculates the 24-hour base CLhT_Diesel VMT from the base hourly MOVES road type and SUT/fuel type VMT and the analysis scenario CLhT_Diesel VMT from the base hourly MOVES road type and SUT/fuel type VMT. The 24-hour analysis scenario CLhT_Diesel VMT is then divided by the 24-hour baseCLhT_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

[29] Previously with MOVES2014, TTI used MOVES default start per vehicle (which varied only by MOVES day type) in combination with local vehicle populations to estimate vehicle starts activity. In MOVES3, vehicle starts per hour also vary by county (because age distributions also vary by county).

scenario hourly CLhT_Diesel SHO (from the SHP calculation process) is converted to hourly VHT fractions. The hourly hotellingfractions are calculated as the inverse of the hourly VHT fractions. The hourly hotellingfractions 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 SHEI fraction and the APU hours 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 source type 62 (CLhT) by ageID (0 through 30) are calculated by multiplying the age distribution by the appropriate relative mileage accumulation rate, which is then turned 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, by model year, to each pertinent operating mode fraction (e.g., for SHEI and APU hours [operating mode IDs 200 and 201]), from the MOVES hotelling activity distribution (also by model year), and summed by operating mode to calculate the composite operating mode fractions (e.g., for operating modes 200 and 201). For each hour the analysis scenario hotelling hours are multiplied by the SHEI fraction to calculate the analysis scenario hourly SHEI activity and by the APU hours fraction to calculate the analysis scenario hourly APU hours activity. The utility also aggregates the hoteling, SHEI, and APU hours activity across hours to produce the daily hoteling, SHEI, and APU hours activity.

MOVES CDB Activity Input Build Module

Using the appropriate SQL code and command script, the activity based input tables are created for all MOVES Inventory Mode CDBs and batch produce the CDBs and MRS files. Section 2.7, Section 3.10 and Section 4.2 described the details of how these on-network activity tables, off-network activity tables and other categories of input tables are populated.

24-Hour and Annual Activity Summarization Module

Using Python code, the hourly activity data obtained from "**HPMS Based Link VMT Module**" and "**Offnetwork Activity Calculation Module"** is scaled, filtered and aggregated to the summer weekday daily and annual average daily activity estimates. The annual average daily estimates are multiplied by 365 to calculate the annual activity estimates. Section 5.4 described the details of the estimation.

24-Hour Rates Adjustment Module

Using Python code, the activity and emission quantity output from MOVES runs are converted to the emission rates and adjusted based on local control programs to calculate summer weekday scenario emission rates and annual scenario average emission rates. Section 5.4 described the details of the emission rate estimation.

Emission Calculation Module

Using Python code, emissions are calculated at a different resolution. The summer weekday activity was multiplied by summer weekday emission rates to calculate the activity based summer weekday emissions for each county and each pollutant. The annual activity was multiplied by the annual average daily emission rates to calculate the activity based annual emissions for each county and each pollutant. Both tab summary files and SCC based XML files were produced for summer weekday scenario and annual scenario. Section 6 of this report described the calculations.

APPENDIX D: TXDOT DISTRICT HOURLY TRAVEL FACTORS (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the hourly travel factors for summary weekday scenario and annual scenario, which were used to distribute 24-hour link VMT estimates to each hour of the day. These hourly travel factors were developed using multi-year (2013 through 2020) aggregated ATR station data for each TxDOT district.

APPENDIX E: TXDOT DISTRICT SEASONAL WEEKDAY AND ANNUAL VMT MIX (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the TxDOT district-level, 24-hour summer weekday on-network and off-network VMT mix data, annual daily on-network and off-network VMT mix data used to estimate vehicle on-network and off-network activities. This end of year 2018 TxDMV vehicle registration data was provided in the form of total vehicles registered by county, aggregated by the vehicle categories.

APPENDIX F: VEHICLE POPULATION ESTIMATES AND 24-HOUR ONI HOURS, SHP, STARTS, SHEI, AND APU HOURS SUMMARIES (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains spreadsheet file with the annual and summer-weekday tabs for: (i) vehicle population, (ii) Adj_SHP, (iii) ONI, (iv) Starts, and (v) Hotelling SHEI APU. Each contain information for all 254 counties.

APPENDIX G: METEOROLOGICAL INPUTS TO MOVES (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains all the necessary meteorological inputs in MOVES-specified formats that were combined in a database for use in building the CDBs for all 254 counties.

APPENDIX H:
COUNTY GROUPS BY ANALYSIS YEAR (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the county groups by analysis years (1990, 1999 – 2002, 2003 – 2005, and 2006 – 2060) which were used to estimate emission rates to be applied to all counties for each respective group.

APPENDIX I: SEASONAL WEEKDAY ON-ROAD AND OFF-NETWORK MOBILE SOURCE EMISSIONS (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the summer weekday on-network and off-network mobile source emissions output.

APPENDIX J: ANNUAL ON-ROAD AND OFF-NETWORK MOBILE SOURCE EMISSIONS (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the annual on-network and off-network mobile source emissions output.

APPENDIX K: TEXAER BASED ON EPA'S EIS NEI CERS XML FORMAT (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.

This Appendix contains the TexAER based on EPA's EIS NEI CERS XML format. The contents of this Appendix was a deliverable for Task 4.