Texas A&M Transportation Institute

Subtask 4.2: Development of Harris County MOVES Emissions Factors for Diesel School Buses by Model Year

Technical Memorandum

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Subtask 4.2: Development of Harris County MOVES Emissions Factors for Diesel School Buses by Model year

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BACKGROUND AND SCOPE OF WORK

On July 24, 2019 TxDOT requested Texas A&M Transportation Institute's (TTI) assistance to provide a method to calculate the emissions benefits of replacing diesel school buses with electric school buses. The calculations are for a pilot project that involves replacing approximately 10 diesel school buses with electric school buses (Type C school bus – 72+ passengers) with average daily commute of 90-150 miles.

The goal of this task is to develop school bus emissions factors by model year using the latest US Environmental Protection Agency MOVES model for the Houston Area in Texas, along with a spreadsheet tool that can be used to estimate emissions benefits from replacing diesel school buses with electric school buses.

TASK OBJECTIVES

The task objectives are as follows:

- Generate school bus emissions rates using the latest MOVES Model.
- Post-process emission rates to produce emission factors for the emissions calculations.
- Develop a Microsoft Excel® workbook to calculate emission benefits.

EMISSION RATES DEVELOPMENT

TTI used MOVES2014a modeling information consistent with Houston-Galveston Area Air Emissions reporting Rule input data to develop the 2020 analysis year emission rates for different school bus model years (1990 through 2030). Additional details on each of the MOVES inputs and methodologies used to estimate emission factors are available in Appendix A. The following is a summary of the inputs used for emission factors estimation:

Emissions Model Version: MOVES2014a.[1]

Analysis Year Runs: 2020 analysis year.

Time Periods: Summer and Winter weekday.

Hours: All

Pollutants Reported: CO, NOx, VOC, PM2.5, PM10, CO2, Priority MSATS.

Functional Class: The four MOVES road types—rural restricted and unrestricted access, urban restricted and unrestricted access; and the MOVES off-network category.

Speed: TTI used the MOVES county-scale/emission rates mode to model urban and rural, restricted and unrestricted access road type emission factors for each of the 16-speed bin average speeds (i.e., 2.5 mph and 5 mph through 75 mph, at 5 -mph increments) for rate lookup tables.

Vehicle Registration: Mid-year Texas Department of Motor Vehicles (TxDMV) registration data by analysis year were used (for age distributions). The latest available (2014) was used for future years.

POST-PROCESSING EMISSIONS RATES

This step involves developing aggregated MOVES emission factors based on speed and roadway type for school buses by model year. MYSQL scripts written such that the hourly emission rates output from MOVES model were post-processed to develop daily

[1] EPA released MOVES2014a in November 2015 and updated it in December 2015, November 2016, and December 2017; the December 2017 MOVES2014a release only corrected a non-road mobile post-processing script. EPA released MOVES2014b August 2018; MOVES2014b improves the non-road component and updates chemical mechanism outputs that do not apply to on-road mobile emission rates used in conformity analyses. TTI used the November 2016 MOVES2014a release.

emission factors using hourly factors[2]. The final output from this task is a summer and winter emission factors as shown in Figure 1.

YEAR	MODELYE	ROADTYPE	ROADDESC	AVGSPEED	CO_GMile	NOX_GMile	VOC_GMile	PM10_GMile
2020	1990	2	Rural-Freeway	2.5	31.26938418	108.8730695	17.60691158	9.692499794
2020	1990	2	Rural-Freeway	5	17.93394893	51.02876586	9.701528948	5.434839949
2020	1990	2	Rural-Freeway	10	10.76160468	30.03329004	5.33128988	3.249740008
2020	1990	2	Rural-Freeway	15	8.391469073	24.22438759	3.88980794	2.563714958
2020	1990	2	Rural-Freeway	20	7.193839844	21.13220154	3.137278056	2.226964943
2020	1990	2	Rural-Freeway	25	6.148727614	18.69357444	2.604363463	1.888400963
2020	1990	2	Rural-Freeway	30	5.531800661	17.58021374	2.267545809	1.712398939
2020	1990	2	Rural-Freeway	35	4.747434689	14.45672563	1.988022559	1.49702803
2020	1990	2	Rural-Freeway	40	4.339985609	13.17021346	1.798220136	1.377447012
2020	1990	2	Rural-Freeway	45	4.013019716	12.12405855	1.648632789	1.281109014
2020	1990	2	Rural-Freeway	50	3.669957139	10.91745122	1.513211243	1.177044993
2020	1990	2	Rural-Freeway	55	3.389274992	9.930347502	1.402407723	1.091902961
2020	1990	2	Rural-Freeway	60	3.103386275	9.074033372	1.293730037	0.999216019
2020	1990	2	Rural-Freeway	65	2.951233828	11.33114596	1.204838485	0.913872999
2020	1990	2	Rural-Freeway	70	2.828407342	13.50672682	1.128992153	0.840303035
2020	1990	2	Rural-Freeway	75	2.730794798	15.74286705	1.063008067	0.777563998
2020	1990	3	Rural-Arterial	2.5	28.22957489	97.84452736	16.4521099	8.357309997
2020	1990	3	Rural-Arterial	5	14.03258184	41.98274294	8.165472742	3.830620067
2020	1990	3	Rural-Arterial	10	7.968217071	24.33386627	4.404325934	2.264730966
2020	1990	3	Rural-Arterial	15	4.057814749	11.88432268	2.536294532	1.067482979
2020	1990	3	Rural-Arterial	20	3.884713283	11.62415974	2.134125461	1.082178025
2020	1990	3	Rural-Arterial	25	3.780860508	11.46818779	1.892846281	1.090995006

Figure 1. Example Emission Factor Tables for Diesel School Buses by Model Year by Function Class and Speed bin.

EMISSIONS CALCULATION SPREADSHEET

Mobile Source Emission Reduction Strategies (MOSERS) formulas and MOVES emission factors were used to estimate emission benefits. The information provided by TxDOT (as agreed) did not include several key inputs, necessary to include a final estimate of emission reductions. Therefore, the research team have developed a simple spreadsheet to enable final emission benefits to be calculated, when these data become available.

[2] The summer and winter weekday and hourly distribution factors were developed using the latest available 10-year, aggregate TxDOT Houston District automatic traffic recorder traffic count data (2008–2017). County-level, summer weekday, hourly travel factors were developed and used to aggregate hourly emission rates to daily emission rates.

The following assumptions were considered for the calculations:

- Average emission factors were developed using summer and winter factors established in previous step
- Urban-Arterial (MOVES = Urban Unrestricted Access) was considered as the roadway type.
- Average speed of 35 mph for daily commute was considered
- Electric busses produce zero emissions.
- For idling emissions rates, 2.5 mph speed emission factors were used (Example calculation, MY 1990 NOx Idling emission rates (g/hour) = 40 g/mile *2.5 mile/hour)
- Stops and starts caused by drop offs are included in the default MOVES school bus drive cycles. The 'extended idling' hours option can be used if there are periods during the actual driving portion of service where buses will be parked with engine running.

The Emissions calculation spreadsheet can be modified with appropriate fleet and activity information (if known) to estimate total emissions reduction.

Table 1 provides an example emissions benefit example for replacing 10 diesel school buses (model year 2000) that travel 120 miles per day and idle for 3 hours per day.

Table 1. Example of Summary of Emissions Reductions Estimates

Project Type	Replacing Vehicle Model Year	Number of Buses	Avg Miles per Day	Idling Hours per Day	NOx (lbs/day)	VOC (lbs/day)
Electric School Bus Replacement for Houston ISD	2000	10	120	3	15.274	4.374

Discussion and Future Work

Based on experiences during this task, the TTI team provides the following recommendations and comments:

- Since electric buses increase the demand on the electric power, in the future such problems may need an assessment of the emissions generated at power plants to balance the on-road emissions savings.
- Accurate emissions estimation needs accurate activity and fleet data. Data such as idling hours, average yearly VMT, starts, etc. are required to develop accurate emissions. Currently there are minimal data specifically describing Texas school bus drive cycles. For this project, national MOVES default values were used.

APPENDIX A- 2020 SUMMER AND WINTER SEASON, WEEKDAY, HARRIS COUNTY MOVES EMISSIONS RATES MODELING DETAILS FOR DIESEL SCHOOL BUSES

Diesel school bus emissions factors will be modeled using a combination of local and default input data to MOVES. The details follow:

- MOVES2014a (with MOVESDB20161117) will be used.
- County: Harris.
- Analysis year: 2020.
- Seasons: summer (June through August), winter (December, January, February).
- Day-type: weekday.
- Hours: All
- Pollutants: 82 MOVES pollutants included in the inventory estimates, including 12 CAPs and CAP precursors and 70 HAPs (see Tables 1 and 2).
- Emissions Processes: Running Exhaust, Crankcase Running Exhaust, Start Exhaust, Crankcase Start Exhaust, Brake Wear, and Tire Wear.
- MOVES runspec files: Two (one for summer, one for winter – see Table 3).
- MOVES CDBs: One (will include input data for both seasons – see Table 4).

- MOVES Output: by fuel type, source type, model year, regulatory class, road type, speed, hour, pollutant, process.
- Emission rate adjustments: NOx (and NO, HONO and NO2) rates should be adjusted to account for TxLED effects (2002 and newer model years -4.8%; 2001 and older model years -6.2%).

Table 2 and Table 3 itemize the pollutants to be included in the MOVES runspecs. The MOVES Runspec selections and CBD tables and data to be included are detailed in Table 3 and Table 4 . The CDB will be based on the Harris County 2017 MOVES CDB developed and used by TTI to produce emission rates for the recent AERR inventory project sponsored by TCEQ.

Table 2. CAPs and CAP Precursors to be Included.

MOVES Pollutant ID	Pollutant Name	NEI Pollutant Code
2	Carbon Monoxide (CO)	CO
3	Oxides of Nitrogen (NO_x)	NOX
30	Ammonia (NH_3)	NH3
31	Sulfur Dioxide (SO_2)	SO2
87	Volatile Organic Compounds (VOC)	VOC
90	Atmospheric CO_2	CO2
100	Primary Exhaust PM_{10} – Total	PM10-PRI
106	Primary PM_{10} –Brakewear Particulate	PM10-PRI
107	Primary PM_{10} – Tirewear Particulate	PM10-PRI
110	Primary Exhaust $PM_{2.5}$ – Total	PM25-PRI
116	Primary $PM_{2.5}$ – Brakewear Particulate	PM25-PRI
117	Primary $PM_{2.5}$ – Tirewear Particulate	PM25-PRI

Table 3. HAPs to be Included.

Category[1]	MOVES Pollutant ID[2]		Pollutant Name[2]	NEI Pollutant Code[2]
Gaseous HC	20		Benzene	71432
	21		Ethanol	64175
	22		MTBE	1634044
	24		1,3-Butadiene	106990
	25		Formaldehyde	50000
	26		Acetaldehyde	75070
	27		Acrolein	107028
	40		2,2,4-Trimethylpentane	540841
	41		Ethyl Benzene	100414
	42		Hexane	110543
	43		Propionaldehyde	123386
	44		Styrene	100425
	45		Toluene	108883
	46		Xylene	1330207
Polycyclic Aromatic HC (PAH)	**Gas**	**PM**		
	170	70	Acenaphthene	83329
	171	71	Acenaphthylene	208968
	172	72	Anthracene	120127
	173	73	Benz(a)anthracene	56553
	174	74	Benzo(a)pyrene	50328
	175	75	Benzo(b)fluoranthene	205992
	176	76	Benzo(g,h,i)perylene	191242
	177	77	Benzo(k)fluoranthene	207089
	178	78	Chrysene	218019
	168	68	Dibenzo(a,h)anthracene	53703
	169	69	Fluoranthene	206440
	181	81	Fluorene	86737
	182	82	Indeno(1,2,3,c,d)pyrene	193395
	185	23	Naphthalene	91203
	183	83	Phenanthrene	85018
	184	84	Pyrene	129000

Category[1]	MOVES Pollutant ID[2]	Pollutant Name[2]	NEI Pollutant Code[2]
Metal	60	Mercury Elemental Gaseous	200
	61	Mercury Divalent Gaseous	201
	62	Mercury Particulate	202
	63	Arsenic Compounds	93
	65	Chromium 6+	18540299
	66	Manganese Compounds	7439965
	67	Nickel Compounds	7440020
Dioxin/Furan	130	1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	19408743
	131	Octachlorodibenzo-p-dioxin	3268879
	132	1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	35822469
	133	Octachlorodibenzofuran	39001020
	134	1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	39227286
	135	1,2,3,7,8-Pentachlorodibenzo-p-Dioxin	40321764
	136	2,3,7,8-Tetrachlorodibenzofuran	51207319
	137	1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673897
	138	2,3,4,7,8-Pentachlorodibenzofuran	57117314
	139	1,2,3,7,8-Pentachlorodibenzofuran	57117416
	140	1,2,3,6,7,8-Hexachlorodibenzofuran	57117449
	141	1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	57653857
	142	2,3,7,8-Tetrachlorodibenzo-p-Dioxin	1746016
	143	2,3,4,6,7,8-Hexachlorodibenzofuran	60851345
	144	1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562394
	145	1,2,3,4,7,8-Hexachlorodibenzofuran	70648269
	146	1,2,3,7,8,9-Hexachlorodibenzofuran	72918219

[1] MOVES models two groups of metal emissions, those used for air quality modeling, and metals due to their known toxicity (i.e., the seven metal species in this table) (See Section 2.3 in *Air Toxic Emissions from On-Road Vehicles in MOVES2014*, EPA, November 2016). The other metals (e.g., iron, aluminum) were not estimated separately as HAPs, but were, by default, included in the aggregate exhaust $PM_{2.5}$ estimates.

[2] These 70 HAPs available in MOVES are the same 70 as identified in Table 1 through 4 of EPA's *Air Toxic Emissions* report. All NEI pollutant codes were taken from the MOVES pollutants table, except for ethanol, which includes a placeholder ID created from the associated CAS number (see Table 1, from the *Air Toxic Emissions* report).

Table 4. Selections by MOVES Graphical User Interface Panel.

Navigation Panel	Detail Panel	Selection		
Scale	Model; Domain/Scale; Calculation Type	On-Road; County; Emissions Rates		
Time Spans	Time Aggregation Level; Years – Months – Days – Hours	Hour; 2020 – January & July – Weekday - All		
Geographic Bounds	Region; Selections; Domain Input Database	Zone and Link; ***Harris County***; ***<COUNTY INPUT DATABASE (CDB) NAME>***		
On-Road Vehicle Equipment	SUT/Fuel Combinations	SUT	Gasoline	Diesel
		Motorcycle		
		Passenger Car		
		Passenger Truck		
		Light Commercial Truck		
		Intercity Bus		
		Transit Bus		
		School Bus		X
		Refuse Truck		
		Single Unit Short-Haul Truck		
		Single Unit Long-Haul Truck		
		Motor Home		
		Combination Short-Haul Truck		
		Combination Long-Haul Truck		
Road Type	Selected Road Types	Off-Network – Rural Restricted Access – Rural Unrestricted Access – Urban Restricted Access – Urban Unrestricted Access		
Pollutants[2] and Processes	VOC; CO; NO_x; SO_2; NH_3; Atmospheric CO_2; PM_{10}	Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust,		

	Total Exhaust, Brakewear, Tirewear; $PM_{2.5}$ Total Exhaust, Brakewear and Tirewear; and the MOVES HAPs (see previous table)	Brakewear, Tirewear (Dependent on pollutant)
Manage Input Data Sets	Additional Input Database Selections	None
Strategies	Rate Of Progress	Not Applicable
General Output	Output Database; Units; Activity	***<MOVES OUTPUT DATABASE NAME>;*** grams, KiloJoules, Miles; Hotelling Hours, Population, Starts (pre-selected)
Output Emissions Detail	Always; For All Vehicles/Equipment; On Road	Time: Hour – Location: Link – Pollutant; Model Year, Fuel Type, Emissions Process; Road Type, Source Use Type, Regulatory Class
Advanced Performance Measures	Aggregation and Data Handling	Check all the "clear …Output after rate calculations" boxes
year	Time	Designates analysis year as a base year (base year means that activity inputs for the analysis are supplied rather than forecast by the model).
state	Geography	Identifies the state (Texas) for the analysis.
county	Geography/ Meteorology	Specifies the county, local altitude, and barometric pressure (use base year 2017 annual average data provided by TCEQ).
zonemonthhour[1]	Meteorology	Local, hourly temperature and relative humidity for the county (use 2017 data for both summer and winter seasons, provided by TCEQ).
roadtype[2]	Activity	Lists the MOVES road types and associated ramp activity fractions. Road type ramp fractions were set to 0.
hpmsvtypeyear[3]	Activity	Used MOVES default national annual VMT by HPMS vehicle type.
roadtypedistribution[3]		Used MOVES default road type VMT fractions.
monthvmtfraction[3]		Used MOVES default month VMT fractions.
dayvmtfraction[3]		Used MOVES default day VMT fractions.
hourvmtfraction[3]		Used MOVES default hour VMT fractions.
avgspeeddistribution[3]		Used MOVES default average speed

		distributions.
sourcetypeyear[3]	Fleet	Used MOVES default national SUT populations.
sourcetypeagedistribution	Fleet	Will leave empty (N/A for model year output)
avft	Fleet	This will be the standard Texas local statewide input data set (i.e., gas/diesel mix) prepared by TTI, but modified for this analysis by setting school bus fuel fractions to 1.0 for diesel and 0.0 otherwise.
zone	Activity	Start, idle, and SHP zone allocation factors. County = zone, and all factors were set to 1.0 (required for county scale analyses).
zoneroadtype	Activity	SHO zone/roadtype allocation factors. County = zone, and all factors were set to 1.0 (required for county scale analyses).
fuelsupply[1]	Fuel	Fuel supply market shares were set to specify one diesel fuel formulation, per seasonal period (summer and winter were included).
fuelformulation[1]	Fuel	The diesel formulation will be the same for both seasons (conventional diesel with 11.0 ppm sulfur).
imcoverage	I/M	Will leave empty (N/A for school buses).
countyyear	Stage II	N/A in analysis (affects refueling emissions) but will include with control program adjustments set to zero.
hotellingactivitydistribution	Activity	Will leave empty (N/A to school buses).

[1] Meteorological and fuels input data will be included for both summer and winter seasons.

[2] In MOVES rates mode, "ramp road type" rates are not available.

[3] Use of a default set of VMT activity, various travel-related factors, and vehicle population inputs for all MOVES runs is basic to the inventory method, e.g., MOVES default activity is normalized in the calculated rates for applicable processes, and actual local activity estimates are used in the external inventory calculations.