CMAQ Emissions Calculator Toolkit

Documentation of Emissions Modeling for the Electronic Open-Road Tolling Tool

This traffic and emissions modeling document supplements the User Guide for the Electronic Open-Road Tolling (EORT) Tool in the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit). It discusses the primary data sources and how the emission datasets for this tool were derived. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses.

For context, the tool's modeling framework consisted of three major components: 1) traffic simulations, 2) emissions modeling, and 3) linear regressions. The traffic simulator produced vehicle trajectories that were transformed into operating mode distributions. These operating mode distributions summarized driving behavior through toll plazas with full stops or reduced speeds and open-road tolling facilities at or near free flow under a range of traffic conditions. The distributions were then used as inputs for the emissions model. Emission rates were calculated for the various tolling facility design and traffic conditions simulated. Finally, multivariable linear relationships between the traffic parameters and emission rates were calculated through regression analysis in order to fill in any data gaps. The resulting regressions enable users to predict emission reductions when converting from legacy tolling infrastructure to EORT systems.

First, the document describes the microscopic, multi-modal traffic simulations conducted through Eclipse Simulation of Urban Mobility (SUMO) to model vehicle trajectories under the full stop, rolling cruise, and free flow tolling scenarios. The document also describes the emissions data obtained from the US Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES).[1] The MOVES Methodology section describes the specific inputs and outputs, pre-processing, and post-processing used to generate the project-level emission rates used within the tool. Lastly, the Multivariable Linear Regressions (MLR) section describes how SUMO and MOVES data were synthesized to construct multivariable linear regression equations for predicting emissions rates based on evaluation year, traffic throughput, average speed, and heavy-duty vehicle (HDV) percentage.

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SUMO TRAFFIC MICROSIMULATIONS

The traffic network editor for Eclipse SUMO (netedit 1.5.0) was used to create a network to simulate a toll plaza under different scenarios. Network, configuration, routing input file parameters were modified according to the tolling scenarios and traffic conditions. After designing the network and defining any configuration and routing assumptions, SUMO's graphical user interface (GUI 1.5.0) was used to run each of the scenarios outlined according to the previously mentioned network, routing, and configuration files.

The base network had a three segment (edges) and a four lane construction (see screenshot in Figure 1). The three segments were built to accommodate an approach zone at highway speed, a full stop or reduced speed zone for the rolling cruise scenario, and an acceleration zone where the vehicle would return to highway speed following the toll booth or gantry. The network file allowed for network route assignment from edge to edge connected by nodes along with assignment of associated travel speeds through the network by edge and node.

Figure 1. SUMO network simulation run – in progress snapshot

The routing file assigned the throughput of vehicles to each of the toll lanes: three lanes were dedicated to light-duty vehicles (LDVs) only and one lane was dedicated to heavy-duty vehicles (HDVs) for a simplified configuration. The throughput of vehicles were input as a rate and assigned start and stop times for vehicle release to the system. Initial speeds for vehicles were entered into the routing file according to the associated scenario by toll lane assignment. In the case of the full stop scenario, stop lane duration was managed by assignment.

The configuration file assigned the network and routing file as inputs and allowed for the generation of an output trajectory file following the simulation run. The simulation completed when all vehicles exited the network.

Output trajectory files containing records with speed, acceleration, and vehicle type identification by time stamp were generated following each run and subsequently used for downstream processing by MOVES (see Figure 2).

```
<trajectories xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/amitran/trajectories.xsd"
    <actorConfig id="4" vehicleClass="Passenger" fuel="Gasoline" emissionClass="Euro4" ref="DEFAULT_VEHTYPE"/>
    <vehicle id="0" actorConfig="4" startTime="0" ref="trip_0"/>
    <motionState vehicle="0" speed="0" time="0" acceleration="0"/>
    <motionState vehicle="0" speed="212" time="1000" acceleration="2120"/>
    <motionState vehicle="0" speed="455" time="2000" acceleration="2432"/>
    <motionState vehicle="0" speed="638" time="3000" acceleration="1826"/>
    <motionState vehicle="0" speed="849" time="4000" acceleration="2110"/>
    <motionState vehicle="0" speed="1096" time="5000" acceleration="2471"/>
    <motionState vehicle="0" speed="1347" time="6000" acceleration="2508"/>
    <vehicle id="1" actorConfig="4" startTime="7000" ref="flow_2.0"/>
    <motionState vehicle="1" speed="2235" time="7000" acceleration="0"/>
    <motionState vehicle="0" speed="1519" time="7000" acceleration="1726"/>
    <motionState vehicle="1" speed="2254" time="8000" acceleration="193"/>
    <motionState vehicle="0" speed="1766" time="8000" acceleration="2471"/>
```

Figure 2. SUMO trajectory output file – sample snapshot

Key Traffic Variables

Some of the traffic conditions in SUMO were varied by run for Electronic Tolling tool development to build out the range of possible results ultimately used to predict emissions, which included the following traffic microsimulation parameters:

- Tolling Scenario
  - Full Stop (LDV idle: 3.8s, HDV idle: 21.0s),
  - Rolling Cruise (average toll speed: 15 mph or 6.7056 m/s)
  - Free Flow (average toll speed: defined as highway vehicle speed)
- Traffic Congestion/Throughput
  - Peak (345 LDV/lane, 115 HDV/lane, 1150 veh/hr total)
  - Non-Peak (216 LDV/lane, 72 HDV/lane, 720 veh/hr total)
  - Overnight (99 LDV/lane, 33 HDV/lane, 330 veh/hr total)
- Highway Vehicle Speed
  - 50 mph (22.352 m/s)
  - 60 mph (31.2928 m/s)
  - 70 mph (26.8224 m/s)
- Heavy-Duty Percentage
  - 10% in a dedicated HDV lane (and three lanes for LDV traffic)

These four variables created the following 27 different combinations of traffic conditions (3 scenarios x 3 throughputs x 3 speeds x 1 HDV percentage) to model in SUMO. Since LDV and HDV traffic was modeled in dedicated lanes and their emissions were calculated independently, the zero HDV traffic cases were not explicitly simulated in SUMO but instead post-processed after the MOVES run. The average speeds through the tolling area are also reported, as shown in Table 1:

Table 1. The full matrix of 27 traffic condition combinations modeled in SUMO

	Scenario	Traffic Congestion	Highway Speed	Average Speed	HDV Percent	Label
1	Free Flow	1150	50	51.343	10	F_50_P_10
2	Free Flow	1150	60	61.879	10	F_60_P_10
3	Free Flow	1150	70	72.417	10	F_70_P_10
4	Free Flow	720	50	51.391	10	F_50_N_10
5	Free Flow	720	60	61.937	10	F_60_N_10
6	Free Flow	720	70	72.472	10	F_70_N_10
7	Free Flow	330	50	51.253	10	F_50_O_10
8	Free Flow	330	60	61.768	10	F_60_O_10
9	Free Flow	330	70	72.278	10	F_70_O_10
10	Full Stop	1150	50	23.937	10	S_50_P_10
11	Full Stop	1150	60	25.997	10	S_60_P_10
12	Full Stop	1150	70	26.440	10	S_70_P_10

13	Full Stop	720	50	46.116	10	S_50_N_10
14	Full Stop	720	60	53.886	10	S_60_N_10
15	Full Stop	720	70	60.860	10	S_70_N_10
16	Full Stop	330	50	46.276	10	S_50_O_10
17	Full Stop	330	60	54.002	10	S_60_O_10
18	Full Stop	330	70	60.985	10	S_70_O_10
19	Rolling Cruise	1150	50	49.083	10	R_50_P_10
20	Rolling Cruise	1150	60	57.835	10	R_60_P_10
21	Rolling Cruise	1150	70	65.917	10	R_70_P_10
22	Rolling Cruise	720	50	49.128	10	R_50_N_10
23	Rolling Cruise	720	60	57.925	10	R_60_N_10
24	Rolling Cruise	720	70	66.053	10	R_70_N_10
25	Rolling Cruise	330	50	49.034	10	R_50_O_10
26	Rolling Cruise	330	60	57.776	10	R_60_O_10
27	Rolling Cruise	330	70	65.920	10	R_70_O_10

Since heavy-duty traffic was in a dedicated toll lane, that lane was simply excluded from the analysis to create an additional 27 combinations with 0% HDV traffic.

For reference, the length of the three toll segment/edge lengths in SUMO are listed out below:

- Toll Approach (Edge1) = 2183.63 m (1.357 mi)
- Toll Area (Edge2) = 24.39 m (0.015 mi)
- Toll Exit (Edge3) = 1643.02 m (1.021 mi)
- Total Length = 3851.04 m (2.393 mi)

Driving behavior for each of these 27 traffic condition combinations was transformed into a unique operating mode distribution, which was used in the project-level MOVES runs for generating emission reductions for potential projects converting from the full stop or rolling cruise scenarios to free flow.

SUMO Vehicle Trajectory Processing for MOVES Runs

In terms of post-processing the SUMO vehicle trajectory file, the latest EPA's MOVES2014b model was utilized to estimate modal, project-level tailpipe emissions and fuel use based on the vehicle-specific power (VSP), speed, and acceleration. In this case, VSP is calculated from the simulated instantaneous speed v_i and acceleration a_i from SUMO, as shown in Equation 1:

$$VSP(v,a)_i = \frac{Av_i + Bv_i^2 + Cv_i^3 + mv_i a_i}{m}, \quad (1)$$

where *A* is the tire rolling resistance coefficient, *B* is the rotational resistance coefficient, *C* is the aerodynamic drag coefficient, and *m* is the vehicle mass. Default road load coefficients *A*, *B*, and *C* and default vehicle mass for a light-duty vehicle (MOVES sourceTypeID 21) and heavy-duty vehicle (MOVES sourceTypeID 62) were derived from the sourceusetypephysics table in the MOVES2014b database, summarized in Table 2 below.

Table 2. Listing of default MOVES2014b road load coefficients and masses for a representative light-duty vehicle (LDV) and a representative heavy-duty vehicle (HDV).

Road Load Coefficients and Vehicle Masses	LDV (sourceTypeID 21)	HDV (sourceTypeID 62)
Tire rolling resistance coefficient A (kW-s/m)	0.156461	1.47389
Rotational resistance coefficient B (kW-s/m2)	0.002002	0
Aerodynamic drag coefficient C (kW-s/m3)	0.000493	0.003682
Vehicle mass m (metric tons)	1.4788	17.1

To use the default road load coefficients above, speed and acceleration must be in the International System (SI) of Units, m/s and m/s2 respectively. To determine differences in driving behavior between scenarios, custom MOVES operating mode distributions were developed. These operating mode distributions form the basis of any project-level energy and emissions

estimates and are dependent on vehicle speed, acceleration, and VSP. The operating modes were assigned by the traffic conditions laid out in Table 3, as reproduced from the MOVES technical documentation of light-duty emission rates.[2]

Table 3 . MOVES operating mode assignments based on VSP, speed, and acceleration for each time step i

Operating Mode(opModeID)	Operation Mode Description	Vehicle-Specific Power (VSP*i*, kW/metric ton)	Vehicle Speed(v*i*, mph)	Vehicle Acceleration (a*i*, mph/s)
0	Deceleration/Braking			a*i* ≤ -2 OR (a*i* < -1 AND a*i*-1< -1 AND a*i*-2 < -1)
1	Idle		-1 ≤ v*i* < 1	
11	Coast	VSP*i* < 0	1 ≤ v*i* < 25	
12	Cruise/Acceleration	0 ≤ VSP*i* < 3	1 ≤ *vi* < 25	
13	Cruise/Acceleration	3 ≤ VSP*i* < 6	1 ≤ v*i* < 25	
14	Cruise/Acceleration	6 ≤ VSP*i* < 9	1 ≤ *vi* < 25	
15	Cruise/Acceleration	9 ≤ VSP*i* < 12	1 ≤ v*i* < 25	
16	Cruise/Acceleration	12 ≤ VSP*i*	1 ≤ v*i* < 25	
21	Coast	VSP*i* < 0	25 ≤ v*i* < 50	
22	Cruise/Acceleration	0 ≤ VSP*i* < 3	25 ≤ v*i* < 50	
23	Cruise/Acceleration	3 ≤ VSP*i* < 6	25 ≤ v*i* < 50	
24	Cruise/Acceleration	6 ≤ VSP*i* < 9	25 ≤ v*i* < 50	
25	Cruise/Acceleration	9 ≤ VSP*i* < 12	25 ≤ v*i* < 50	
27	Cruise/Acceleration	12 ≤ VSP*i* < 18	25 ≤ v*i* < 50	
28	Cruise/Acceleration	18 ≤ VSP*i* < 24	25 ≤ v*i* < 50	
29	Cruise/Acceleration	24 ≤ VSP*i* < 30	25 ≤ v*i* < 50	
30	Cruise/Acceleration	30 ≤ VSP*i*	25 ≤ v*i* < 50	
33	Cruise/Acceleration	VSP*i* < 6	50 ≤ v*i*	
35	Cruise/Acceleration	6 ≤ VSP*i* < 12	50 ≤ v*i*	
37	Cruise/Acceleration	12 ≤ VSP*i* < 18	50 ≤ v*i*	
38	Cruise/Acceleration	18 ≤ VSP*i* < 24	50 ≤ v*i*	
39	Cruise/Acceleration	24 ≤ VSP*i* < 30	50 ≤ v*i*	
40	Cruise/Acceleration	30 ≤ VSP*i*	50 ≤ v*i*	

MOVES METHODOLOGY

MOVES2014b project-level runs were used to determine how driving behavior would affect emissions and fuel use depending on the various traffic conditions noted above, including tolling scenario, traffic throughput, highway speed, and heavy-duty traffic. The SUMO vehicle trajectories for each unique combination of traffic conditions was aggregated into a MOVES operating mode distribution, as explained in the section below. These operating mode distributions formed the basis of project-level inputs to determine average emission rates for every traffic condition combination. A series of national-scale MOVES runs were completed first to generate default values for the subsequent project-level runs, as described in greater detail below.

MOVES Parameters

In order to run MOVES at the project level, some national-scale runs (Table 4) were first completed. This allowed default data to be used as inputs for the project-scale runs (Table 5a). Simulated vehicle trajectory files from SUMO were developed into custom operating mode distributions and then used as inputs to MOVES. The national defaults were later adopted as inputs for the Project Data Manager (Table 5b).

Table 4: National-Scale Run Specifications

Category	Variable	Input
Description	-----	<blank>
Scale	Model	Onroad

	Domain/Scale	National
	Calculation Type	Inventory
Time Spans	Time Aggregation Level	Year
	Years	[2020, 2025, 2030]
	Months	All Selected
	Days	All Selected
	Hours	All Selected
Geographic Bounds	-----	Nation
Vehicles/Equipment	On-Road Vehicle Equipment	All Fuel/Type Combinations Selected
Road Type	Road Type	All Road Types
Pollutants and Processes	Total Gaseous Hydrocarbons	Running Exhaust, Crankcase Running Exhaust
	Non-methane Hydrocarbons	Running Exhaust, Crankcase Running Exhaust
	Volatile Organic Compounds	Running Exhaust, Crankcase Running Exhaust
	Carbon Monoxide (CO)	Running Exhaust, Crankcase Running Exhaust
	Oxides of Nitrogen (NOx)	Running Exhaust, Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust
	Primary Exhaust PM2.5 – Total	Running Exhaust, Crankcase Running Exhaust
	Primary Exhaust PM2.5 – Species	Running Exhaust, Crankcase Running Exhaust
	Primary PM2.5 – Brakewear Particulate	Brakewear
	Primary PM2.5 – Tirewear Particulate	Tirewear
	Primary Exhaust PM10 – Total	Running Exhaust, Crankcase Running Exhaust
	Primary Exhaust PM10 – Species	Running Exhaust, Crankcase Running Exhaust
	Primary PM10 – Brakewear Particulate	Brakewear
	Primary PM10 – Tirewear Particulate	Tirewear
	Carbon Dioxide Equivalent (CO2e)	Running Exhaust
	Total Energy Consumption (TEC)	Running Exhaust
Manage Input Data Series	-----	<blank>
Strategies	Rate of Progress	<blank>
General Output	Units	Mass: kilograms, Energy: million BTU, Distance: miles
	Activity	Source Hours Operating
Output Emissions Detail	Always	Year, Nation
	On Road/Off Road	Road Type
	For All Vehicle/Equipment Combinations	Model Year
Advanced Performance Features	-----	<blank>

Users that are importing their own emission rates do not need to complete national-scale runs if they have all the local data necessary for project-level analysis. The generic parameters used in project-scale runs can be found in Table 5a. Note that only three evaluation years (2020, 2025, 2030) were run because the MLRs were able to predict the emission rates for all other modeling parameters using the following independent variables: evaluation year, traffic throughput, average speed, and HDV traffic.

Table 5a: Project-Scale Run Specifications

Category	Variable	Input
Description	-----	<blank>

Scale	Model	Onroad
	Domain/Scale	Project
	Calculation Type	Inventory
Time Spans	Time Aggregation Level	Year
	Years[3]	2020, 2025, 2030
	Months	January
	Days	Weekdays
	Hours	00:00 – 00:59
Geographic Bounds	Region	Custom Domain
	State ID:	99
	County ID:	1
	GPA Fraction	0.0
	Bar. Pressure	28.94
	Vapor Adjust	0.0
	Spill Adjust	0.0
Vehicles/Equipment	On-Road Vehicle Equipment	Combination Long-haul Truck, Passenger Car
Fuel Type	-----	Diesel, Electricity, Ethanol (E-85), Gasoline
Road Type	Road Types	Rural Restricted Access[4]
Pollutants and Processes (selected)	Total Gaseous Hydrocarbons	Running Exhaust, Start Exhaust
	Non-methane Hydrocarbons	Running Exhaust, Start Exhaust
	Volatile Organic Compounds	Running Exhaust, Start Exhaust
	Methane (CH4)	Running Exhaust, Start Exhaust
	Carbon Monoxide (CO)	Running Exhaust, Start Exhaust
	Oxides of Nitrogen (NOx)	Running Exhaust, Start Exhaust
	Nitrous Oxide (N2O)	Running Exhaust, Start Exhaust
	Primary Exhaust PM2.5 – Total	Running Exhaust, Start Exhaust
	Primary Exhaust PM2.5 - Species	Running Exhaust, Start Exhaust
	Primary PM2.5 – Brakewear Particulate	Brakewear
	Primary PM2.5 – Tirewear Particulate	Tirewear
	Primary Exhaust PM10 – Total	Running Exhaust, Start Exhaust
	Primary PM10 – Brakewear Particulate	Brakewear
	Primary PM10 – Tirewear Particulate	Tirewear
	Total Energy Consumption	Running Exhaust, Start Exhaust
	Atmospheric CO2	Running Exhaust, Start Exhaust
	CO2 Equivalent	Running Exhaust, Start Exhaust
Manage Input Data Series	-----	<blank>
Strategies	Rate of Progress	<blank>
General Output	Units	Mass: kilograms Energy: million BTU Distance: miles
	Activity	Distance Traveled, Source Hours Operating, Population
Output Emissions Detail	Always	<blanked out>
	On Road/Off Road	Road Type, Source Use Type
	For All Vehicle/Equipment Combinations	Model Year, Fuel Type

Advanced Performance Features	-----	<blank>

The MOVES project-scale runs utilized a series of inputs from the national-scale runs outlined in Table 4 and from the MOVES default database. Data entered into each Project Data Manager tab has been recorded in Table 5b.

Table 5b. Project Data Manager – Inputs by Tab

Data	Source
Age Distribution	Adopted MOVES2014a default age distributions for all evaluation years from 2020, 2025, and 2030 (taken from sourcetypeagedistribution table in movesdb20161117 database)
AVFT [5]	Pulled table from movesexecution database in national-scale inventory run for 2020
Fuel Formulation	Pulled table from moves default database (movesdb20161117) for 2020
Fuel Supply	Pulled table from moves default database (movesdb20161117) for all evaluation years (2020, 2025, and 2030)
Fuel Usage Fraction	Pulled table from moves default database (movesdb20161117) for all evaluation years (2020, 2025, and 2030)
Generic	---
Hotelling	---
I/M Programs[6]	Used imcoverage table from movesexecution database in national-scale inventory run for all evaluation years (2020, 2025, and 2030)
Links	Customized input with the following data: • linkID: roadTypeID concatenated with linkAvgSpeed (i.e., 200, 201, 202â€¦ 275) • countyID: 99001 • zoneID: 1 • roadTypeID: 2 • linkLength: 2.393 mi • linkVolume: corresponds to toll throughput • linkAvgSpeed: corresponds to average speed reported by SUMO • linkDescription: each combination has a concatenated label with its respective traffic conditions (e.g. F_70_P_10 indicates a SUMO run under the free flow scenario, 70 mph, peak throughput, and 10% HDV traffic) • linkAvgGrade: 0
Link Source Type	Customized input with the following data: • linkID: 1 through 27 • sourceTypeID: 21, 62 • sourceTypeHourFraction: Ran two different HDV percentages: 0% and 10%; remaining traffic assumed to be LDVs, 100% and 90%, respectively
Meteorological Data[7]	Customized input with the following data: • monthID: 1 • zoneID: 1 • hourID: 1 Copied temperature and relHumidity from zonemonthhour table in the movesexecution database of national-scale inventory run for 2020
Off-Network	---
Operating Mode Distribution	Customized input with the following data: • sourceTypeID: 21 or 62, depending on the specific distribution • hourDayID: 15 • linkID: 1-27 • polProcessID: 101, 201, 301, 501, 601, 9101, 11201, 11609, 11710, 11801 • opModeID: 0-40 (as detailed in Table 3); 501 (always has a zero fraction) • opModeFraction: each fraction is calculated from the aggregated SUMO vehicle trajectory data
Retrofit Data	---
Tools	---
Zone	Customized input with the following data: • zoneID: 1 • countyID: 99001

	• all allocation factors (startAllocFactor, idleAllocFactor, and SHPAllocFactor) have been set to 1
Zone Road Type	Customized input with the following data: • zoneID: 1 • roadTypeID: 2 • SHOAllocFactor: set to 1

If desired, users may do their own modeling, such that they do not need to follow the default inputs used in the Project Data Manager above and can develop the necessary project-level inputs from local data.

Post-MOVES Run Data Processing

Results from the project-level MOVES runs described above were used to obtain data for use in the EORT Tool. The following section describes how MOVES activity and emissions inventory data were used to develop the tool's emissions rates.

Light- and heavy-duty vehicle emission rates were calculated separately using otherwise identical procedures: light-duty rates are for passenger vehicles (sourceTypeID 21); heavy-duty rate are for heavy-duty combination trucks (sourceTypeID 62). Brake and tire wear were aggregated into the particulate matter (PM) results for both sets of rates.

- **Activity rates –** To obtain project-level activity rates, the distance travelled (activityType1) was extracted from the results for all vehicles.
- **Hourly emissions –** Emission rates were generated on a per-mile basis. This involved joining emission inventories from the movesoutput table and activity from the movesactivityoutput. To determine emission rates, all running emissions were divided by distance travelled.

Separate emission rates were computed for project evaluation year, tolling scenario, pollutant, highway speed, traffic throughput, and vehicle type (either LDV or HDV). Rates were then aggregated into two broad categories: 1) mixed traffic with 10% HDV and 90% LDV traffic, and 2) LDV only (to represent 0% HDV traffic).

MULTIVARIABLE LINEAR REGRESSIONS

Using SUMO and MOVES data, 21 MLR equations were constructed (3 scenarios x 7 pollutants). Each equation is based on 18 data points and predicts the emission rate by pollutant based on evaluation year, traffic throughput, average speed, and HDV percentage. The MLRs for tolling emission rates E all take the same general form as Equation 2 below, which is dependent on scenario and pollutant for consistency and comparability:

$$E = k_{q_{scen,pol}} \cdot q + k_{s_{scen,pol}} \cdot s + k_{\alpha_{scen,pol}} \cdot \alpha + k_{y_{scen,pol}} \cdot y + K_{scen,pol} \quad (2)$$

where,

$k_{q_{scen,pol}}$ = regression coefficient for toll throughput by scenario and pollutant,

$k_{s_{scen,pol}}$ = regression coefficient for average speed by scenario and pollutant,

$k_{a_{scen,pol}}$ = regression coefficient for heavy-duty traffic through tolling facility by scenario and pollutant,

$k_{y_{scen,pol}}$ = regression coefficient for evaluation year by scenario and pollutant,

$K_{y_{scen,pol}}$ = regression y-intercept by scenario and pollutant,

q = user-supplied input for hourly toll throughput per lane (veh/ln/hr),

s = user-supplied average speed through tolling facility (mph),

a = user-supplied input for percentage of heavy-duty vehicle traffic, and

y = project evaluation year.

All regression equations have a strong goodness of fit (multiple R2 = 0.823–0.989), all many of the pollutants have lower correlations for the full stop scenarios. All predictive variables were included in each MLR equation for consistency between scenarios, as shown below in Table 4.

Table 4. Multivariable linear regression (MLR) coefficients and associated correlation coefficients

Scenario	Pollutant	Mult. R2	Adj. R2	y-Intercept	Traffic Congest Coef.	Avg. Speed Coef.	HDV Percent Coef.	Year Coeff.
F	CO	0.9467	0.9423	2.607E-01	1.039E-08	3.155E-05	-5.587E-05	-1.286E-04
F	NOx	0.9122	0.905	2.147E-01	1.122E-08	1.222E-05	2.431E-04	-1.063E-04
F	VOC	0.9104	0.9031	1.115E-02	-3.622E-11	-2.754E-07	9.159E-06	-5.485E-06
F	PM2.5	0.8936	0.8849	6.650E-03	1.069E-09	-9.540E-08	6.898E-06	-3.279E-06
F	PM10	0.8936	0.8849	7.242E-03	1.160E-09	-1.039E-07	7.489E-06	-3.572E-06
F	CO2e	0.9893	0.9884	1.403E+01	5.193E-06	4.314E-03	6.249E-02	-6.942E-03
F	Energy	0.9893	0.9884	1.895E-01	6.728E-08	5.564E-05	7.985E-04	-9.369E-05
S	CO	0.8468	0.8343	3.589E-01	9.423E-07	1.542E-05	-8.839E-05	-1.763E-04
S	NOx	0.836	0.8226	2.880E-01	7.794E-07	-1.265E-05	3.319E-04	-1.421E-04
S	VOC	0.839	0.8258	1.467E-02	2.032E-08	-1.023E-06	1.200E-05	-7.215E-06
S	PM2.5	0.8228	0.8084	1.136E-02	2.019E-08	-7.799E-07	1.155E-05	-5.596E-06
S	PM10	0.8228	0.8083	1.238E-02	2.194E-08	-8.477E-07	1.254E-05	-6.098E-06
S	CO2e	0.8797	0.8699	1.758E+01	2.877E-04	-4.083E-03	8.954E-02	-8.546E-03
S	Energy	0.879	0.8691	2.379E-01	3.706E-06	-5.272E-05	1.145E-03	-1.157E-04
R	CO	0.9581	0.9547	3.357E-01	1.098E-08	4.837E-05	-9.543E-05	-1.656E-04
R	NOx	0.9101	0.9028	2.463E-01	1.475E-08	2.045E-05	2.803E-04	-1.222E-04
R	VOC	0.9127	0.9056	1.200E-02	1.465E-10	-1.081E-07	9.392E-06	-5.910E-06
R	PM2.5	0.8944	0.8857	9.320E-03	7.743E-10	1.364E-07	9.352E-06	-4.604E-06
R	PM10	0.8944	0.8858	1.016E-02	8.498E-10	1.488E-07	1.015E-05	-5.018E-06
R	CO2e	0.9857	0.9845	1.535E+01	5.982E-06	7.760E-03	7.562E-02	-7.668E-03

These regression coefficients and correlation statistics as well as the underlying traffic and emissions data can be unhidden (in Excel by right-clicking on any tab in the tool and selecting to Unhide the Emission_Rate_MLRs and EORT_Lookup_Data sheets, respectively) and can be changed if a user wishes to supply their own emissions data for this tool. Users should already have project-specific traffic microsimulation and project-level emission rate results prior to trying any MLR development on their own.

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1 US Environmental Protection Agency, Office of Transportation and Air Quality, https://www.epa.gov/moves

2 Exhaust Emission Rates for Light-Duty On-Road Vehicles in MOVES2014. Publication EPA-420-R-15-005. Environmental Protection Agency, 2015 (https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NNVN.pdf).

3 To avoid an excessively large output database, only three evaluation years were run, the rest have been predicted using multivariable linear regressions (MLRs).

4 Road type selected does not matter when entering custom operating mode distributions for a project-level MOVES run.

5 Alternative Vehicle Fuel Technology. Note that national-scale MOVES runs were used to populate the AVFT table, as it is not populated in the MOVES default database. If needed, please follow the parameters laid out in Table 3 for the national-scale runs.

6 Inspection and Maintenance Programs. Note that national-scale MOVES runs were used to populate the I/M Program table, as it is not populated in the MOVES default database. If needed, please follow the parameters in Table 1 for the national-scale runs.

7 Note that national-scale MOVES runs were used to populate the meteorological data table, as it is not populated in the MOVES default database. If needed, please follow the parameters laid out in Table 1 for the national-scale runs.