CMAQ EMISSIONS CALCULATOR TOOLKIT

The purpose of the Congestion Mitigation and Air Quality Improvement Program Emissions Calculator Toolkit (CMAQ Toolkit) is to provide users a standardized approach to estimating emission reductions from the implementation of a CMAQ-funded project. The CMAQ Toolkit uses emission rates for highway vehicles based on a series of project-scale and national-scale runs of the Motor Vehicle Emission Simulator (MOVES) as well as other data sources. For each tool in the toolkit, the inputs and methodology are described in user guides along with some example cases. Emission estimates from the CMAQ Toolkit are not intended to meet specific requirements for State Implementation Plans (SIPs) or transportation conformity analyses. Information regarding the development of default emission rates and guidance on incorporating user-supplied emission rates can be found in the accompanying documentation of the emissions data.

Mid-Block Two-Way Left Turn Lane Module

The two-way left turn lane (TWLTL) project emission reductions calculator estimates the emissions benefits from converting the an unseparated median of a segment of roadway between two major intersections, either signalized or stop-sign controlled, into a two way left turn lane. These facilities provide access to driveways, parking lots, or minor roadways for vehicles turning left in either direction of the main roadway.[1]

This module is not intended to estimate benefits from implementing turning lanes or turning phases at signalized intersections. The module is also configured to only estimate emissions benefits from a single segment of roadway between two major intersections. The subject segment may provide access to any number of driveways, business parking lots, or minor roadways. If a TWLTL facility will span several segments of road that encompasses more than two major intersections, emissions benefits should be calculated separately for each segment.

Emissions reductions for these facilities are predicted to result from removing left-turning vehicles from the through lanes on the major roadway, thereby reducing delay to through vehicles and reducing delay to left turning vehicles by increasing gaps between through vehicles in the opposing travel direction. Emission reductions are estimated by calculating the change in running emissions from an improved travel time along the corridor for through-traveling vehicles. It also accounts for reductions in delay for left turning vehicles. The improved travel time is calculated by estimating the change in delay at each access point along the segment, and then multiplying by the total segment volume to travel speed in each direction.[2] Running emissions for the average speed associated with the existing and the improved

[1] The most current version of the tool is dated June 2022. To verify the version, check the date on the Introduction page of the tool. Release notes are included in the Change Log tab, which can be viewed by right-clicking on any tab in the tool, selecting “Unhide”, and revealing the tab.

[2] Roadway performance calculations rely on a methodology for predicting through and left turning vehicle delay developed for NCHRP Report number 395, Capacity and Operational Effects of Midblock Left-Turn Lanes. This methodology was developed using regression analyses performed on data from traffic micro-simulations.

travel time, as well as idling emissions changes for left-turning vehicles, are compared to estimate emissions benefits.

This document is organized into three sections – User Guide, Tool Methodology, and Examples – to aid the user in understanding and interpreting results from the calculator. The User Guide directs the user on how to properly input values into the tool, and provides definitions of both user inputs and tool outputs. The Tool Methodology section outlines the steps taken by the tool to calculate emission reductions, as well as any assumptions incorporated into the tool. This section also describes the equations used within the tool to calculate emission benefits. The Examples section provides instructive examples of how to use the tool for project analysis.

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USER GUIDE

This section lists the units and description for each user input and tool output, as well as a description of emission reductions reporting and error messages.

User Inputs

The TWLTL Module contains a series of questions to guide the user in properly inputting information for emission reductions calculations in a step-by-step process. The inputs for this tool should be specific to the vehicles and road types involved in the project.

Table 1. User Inputs

User Input	Units	Description
Evaluation year	-----	Use the drop-down menu to choose a year between 2018 and 2040.
Area type	-----	Use the drop-down menu to choose the appropriate area type for the coordinated signalized corridor. Available area types are: rural and urban, indicating rural and urban unrestricted road types.
Segment length	miles	Input the length of the project segment along which the unseparated median will be converted to a TWLTL. The default value is 1 quarter of a mile (0.25).
Number of lanes (both directions)	-----	Choose the number of through travel lanes in both directions in the roadway segment. The methodology allows for only three choices for this input: 2, 4, or 6.
Free flow speed (speed limit)	mph	Input the average speed limit posted along the length of the project corridor. This is used as the mid-segment (between signals) free-flow speed. The tool's upper limit is 75 mph.
Total peak hours per day (AM+PM)	hours	Input the total number of peak hours the project corridor experiences on a typical weekday. The default value is 4 hours.[3]

The following inputs should be provided for each direction on the major street in the study segment.

Table 2. User Inputs for each travel direction on the major street.

User Input	Units	Description
Number of access points (outside/right side of direction)	-----	Input the number of driveways, parking lot entrances, or minor streets that intersect the major street on the right side or outside of the subject travel direction within the study segment.

[3] https://nacto.org/publication/urban-street-design-guide/design-controls/design-hour/

User Input	Units	Description
Average percent of right turning vehicles per access point	-----	Input the percentage of vehicles approaching each access point intersection that turn right, averaged over the entire major road segment.
Average percent of left turning vehicles per access point	-----	Input the percentage of vehicles approaching each access point intersection that turn left, averaged over the entire major road segment.
Truck Percentage	-----	Input the percentage of traffic averaged over the entire segment that is made up of heavy duty trucks.
Peak hour traffic volume (each direction)	vehicles/hour	Input the peak hour traffic volume or demand on the study segment, averaged over the entire length of the segment.
Annual average daily traffic (AADT, each direction)	vehicles	Input the AADT on the study segment.

Tool Outputs

Once the input parameters are entered, click the 'Calculate Output' button to generate results. Emission results will not automatically update: if any changes are made to the input parameters, this button must be clicked again to calculate updated emission reductions. If you would like to return to default settings and clear input values, click on the 'Reset to Default Values' button.

Emission reductions are calculated for five pollutants – carbon monoxide (CO), particulate matter < 2.5 µm ($PM_{2.5}$), particulate matter < 10 µm (PM_{10}), nitrogen oxides (NOx), and volatile organic compounds (VOC) – in kilograms per day. Reductions in atmospheric carbon dioxide, carbon dioxide equivalents (CO_2e), and total energy consumption (million BTU) are also provided. These parameters are outputs from MOVES related to greenhouse gas reporting.

Note that a '0' value for an emission reduction indicates no change in emissions associated with the project. A negative emissions reduction indicates a disbenefit (i.e., the project increases emissions for a particular pollutant).

Table 3. Proposed Conditions for peak and off-peak hours for each travel direction

Output	Units	Description
Volume (all lanes)	veh/hr	The average hourly volume of traffic for the subject direction in the peak or off-peak time period.
Existing Average Through Vehicle Speed	miles per hour	The calculated through vehicle speed based on the predicted average delay per vehicle and assuming the speed limit is the speed with zero delay.
Left Turn Delay Reduction (left turning vehicles)	seconds per vehicle	Using the methodology explained below, the predicted average delay reduction for left turning vehicles from installing a TWLTL across all left turning vehicles on the segment.

Output	Units	Description
Travel Time Savings (all vehicles)	minutes per day	Using the methodology explained below, the calculated travel time savings (reduction in delay from coordinated signals) during peak-hour conditions.
Proposed Average Through Vehicle Speed	miles per hour	Using the methodology explained below, the calculated corridor average traveling speed calculated from free-flow speed and the calculated average delay across all segment approaches, based on peak and off-peak volume and road capacity.

Error Messages

Table 3 below lists error messages the user may encounter in this tool, the reason for the error message, and the solution. Once you correct any errors, please press 'Calculate Output' to recalculate the results.

Table 4. Error Messages

Error Message	Reason for Error	Solution
You have not entered a valid evaluation year. Please revise before proceeding.	There is no selected evaluation year	Select an evaluation year
Roadway is over capacity. Please correct traffic volume inputs or number of lanes before proceeding.	The volume to capacity ratio for one of the subject segment travel lanes is greater than one.	Adjust number of lanes or traffic volume to remedy volume-to-capacity ratio.
You have not entered a valid road type. Please revise before proceeding.	There is not a valid road type selected.	Select a valid road type
Peak Hour Volume or AADT is zero in one of the directions. Enter a non-zero value for all of these inputs to calculate results.	Traffic volume inputs are zero in one or more of the volume inputs.	No adjustment necessary if these are operating conditions; if this is not correct, please adjust travel time along corridor.
AADT cannot be less than total volume of all peak hours. Please revise before proceeding.	Peak-hour volume times the number of peak hours is greater than the reported total daily traffic.	Adjust peak-hour volume, number of peak hours, or AADT.
Non-peak volume cannot be greater than peak hour volume. Please revise before repeating.	Non-peak hourly volume is calculated as greater than peak hour volume based on AADT, peak hour volume, and total peak hours.	Adjust peak-hour volume, number of peak hours, or AADT.

TOOL METHODOLOGY

Delay Reduction Calculation Methodology

The delay reduction calculations for through vehicles and left turning vehicles in the un-treated and treated scenarios for the TWLTL module are based on NCHRP Report 395 by Bonneson and McCoy from the University of Nebraska, published in 1997. The authors used traffic microsimulations of a model roadway segment with various parameters to produce a dataset that relates the input parameters of the tool to delay experienced by vehicles using the corridor. See this report for a complete description of how this methodology was developed.

The regression analysis described in the report produced two main regression equations: one that calculates delay to through traveling vehicles, and one that calculates delay to left turning vehicles. For through turning vehicles, the following equation applies:

$$d_T = b_0 \times f_L \times f_T \quad (1)$$

With:

$$f_L = b_1 + (1 - x)x^{b_2} \quad (2)$$

$$f_T = \frac{y}{1 - y} \quad (3)$$

$$x = \frac{v_L}{1,800\left(1 - \frac{V_{N,o}}{C_m}\right)} \leq 1.0 \quad (4)$$

$$y = \frac{V - v_L - v_R}{1,800\left[\frac{N}{2} - x(1 - I_{TR})\right]} \quad (5)$$

Where:

d_T = average through vehicle delay per approach in the subject direction of travel, s/v/a

f_L = effect of left-turn volume on through delay

f_T = effect of through volume on through delay

x = variable relating left-turn volume to opposing flow rate

y = variable relating through volume to number of traffic lanes

v_L = average left-turn volume per access point (=V_L/n), vph/access point

V_L = total number of vehicles turning left from the major street in the subject direction of travel (at all access points), vph

v_R = average right-turn volume per access point (= V_R/n), vph/access point

V_R = total number of vehicles turning right from the major street in the subject direction of travel (at all access points), vph

V = total volume in subject direction (= V_N * N/2), vph

V_N = through lane flow rate in subject direction (i.e., the count of lefts, throughs, and rights on the major-street approach to each access point divided by the number of approach lanes, averaged for all access points), vphpl

$V_{N,o}$ = through lane flow rate in the opposing direction, vphpl

N = number of through traffic lanes on the major street (both directions)

n = number of access points located on the outside (right side) of the major street in the subject direction of travel

C_m = constant (900 for undivided cross sections; 1,000 otherwise)

I_{TR} = indicator variable (1.0 for TWLTL treatments; 0.0 otherwise)

b_0, b_1, b_2 = regression parameter coefficients.

The regression parameter values are shown in the following table for un-treated and TWLTL roadway segments:

Coefficient	**Untreated value**	**TWLTL value**
b_2	0.271	1.540
b_1	0.215	0.203
b_0	1.890	1.130

Existing average travel speed is calculated using the user input free flow speed (speed limit) and untreated scenario regression coefficients and variable values. New travel speeds are calculated using the TWLTL regression coefficient values. Emissions benefits for through traveling vehicles in each subject direction are thus calculated as:

$$\Delta E = V \times L \times (e_{speed,untreated} - e_{speed,TWLTL}) \quad (6)$$

Where:

ΔE = Change in emissions for through vehicles,

$e_{speed,untreated}$ = the emission rate at the travel speed in the untreated scenario in kg/mile,

$e_{speed,TWLTL}$ = the emission rate at the travel speed in the untreated scenario, and

L = The length of roadway

For left turning vehicles, a slightly different set of equations is used:

$$d_L = \begin{cases} b_0 u(1 + x^{b_2}) & : if\ v_L > 0 \\ 0.0 & : if\ v_L = 0 \end{cases} \quad (7)$$

With:

$$u = \frac{3,600}{V_o e^{(-V_o g/3,600)}} \quad (8)$$

$$g = \begin{cases} b_1 & : if\ N = 4 \\ b_3 & : if\ N = 6 \end{cases} \quad (9)$$

Where:

d_L = average total left-turn vehicle delay per approach in the subject direction of travel, s/v/a

x = variable relating left-turn volume to opposing flow rate (= v_L * u/3,600)

v_L = average left-turn volume per access point (= V_L /n), vph/access point

V_L = total number of vehicles turning left from the major street in the subject direction of travel (at all access points), vph

n = number of access points located on the outside (right side) of the major street in the subject

direction of travel Vo = total volume in the opposing direction (= V_N,o * N/2), vph

$V_{N,o}$ = through lane flow rate in the opposing direction, vphpl

N = number of through traffic lanes on the major street (both directions)

b_0, b_1, b_2, b_3 = regression parameter coefficients.

The regression parameter values are shown in the following table for un-treated and TWLTL roadway segments:

Coefficient	Untreated value	TWLTL value
b_3	5.27	5.21
b_2	0.391	0.667
b_1	6.2	6.35
b_0	0.231	0.292

Delay for left turning vehicles is assumed to occur when the vehicles are waiting for a gap in opposing traffic to execute the turning movement. Thus, once left turning vehicle delay is calculated for the untreated and TWLTL scenarios, emissions benefits are calculated as:

$$\Delta E = V \times e_{idling} \times (d_{L,untreated} - d_{L,TWLTL}) \quad (6)$$

Where:

e_{idling} = the emission rate at idling speeds

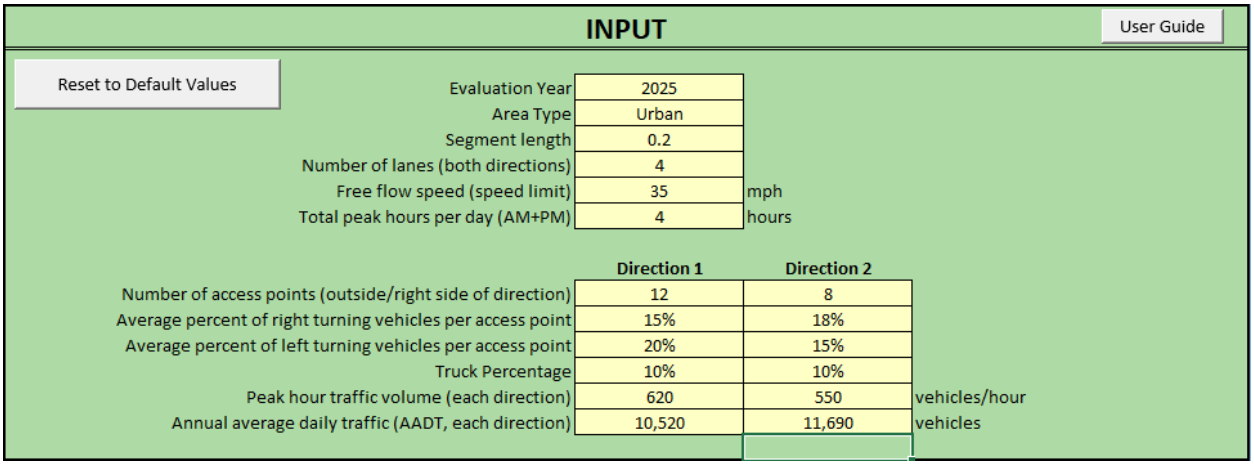
Emissions benefits estimates are combined for each direction and for each time period category, peak or non-peak, to produce the final output, with the total outputs per day accounting for all peak hours and all non-peak hours.

EXAMPLE

Urban Undivided Median Conversion to TWLTL

A municipality is considering converting a 0.2 mile segment of roadway with an undivided median to a TWLTL. The corridor runs through a business district with a number of shops with large parking lots on either side of the major roadway.

Using this information, the user would enter the following inputs into the tool to analyze the scenario, as shown below:



Project evaluation year: 2025
Area type: Urban
Segment length: 0.2 miles

Number of lanes: 4
Free flow speed: 35 mph

For direction one and direction 2 of this roadway segment, the inputs are as follows:

Input	Direction 1	Direction 2
Number of access points (outside/right side of direction)	12	8
Average percent of right turning vehicles per access point	15%	18%

Average percent of left turning vehicles per access point	20%	15%
Truck Percentage	10%	10%
Peak hour traffic volume (each direction)	620	550
Annual average daily traffic (AADT, each direction)	10,520	11,690

Pressing the "Calculate Output" button produces the following results:

OUTPUT Calculate Output

PERFORMANCE

	Direction 1		Direction 2		
	PEAK-HOUR	OFF-PEAK	PEAK-HOUR	OFF-PEAK	
Volume (all lanes)	620	402	550	474.5	veh/hr
Existing Average Through Vehicle Speed	32	33	32	33	mph
Left Turn Delay Reduction (left turning vehicles)	0.6	0.6	0.6	0.6	s/veh
Travel Time Savings (all vehicles)	74	140	56	195	min/day
Proposed Average Through Vehicle Speed	34	34	34	34	mph

EMISSION REDUCTIONS

Pollutant	Peak-hour Kilograms/day	Off-Peak Kilograms/day	Total Kilograms/day
Carbon Monoxide (CO)	3.678	10.752	14.430
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.111	0.231	0.343
Particulate Matter <10 µm (PM_{10})	0.125	0.262	0.387
Nitrogen Oxide (NOx)	2.886	5.556	8.442
Volatile Organic Compounds (VOC)	0.878	2.733	3.611
Atmospheric Carbon Dioxide (CO2)	1,841.711	5,987.223	7,828.934
Carbon Dioxide Equivalent (CO2e)	1,859.330	6,039.325	7,898.655
Total Energy Consumption (MMBTU)	24.183	78.745	102.929

The total daily emission reductions in kg/day and TEC reductions in millions of British Thermal Units (MMBTU) are:

Carbon Monoxide (CO): 14.430
Particulate Matter (PM2.5): 0.343
Particulate Matter (PM10): 0.387
Nitrogen Oxide (NOx): 8.442
Volatile Organic Compounds (VOC): 3.611

Atmospheric CO_2: 7,828.934
Carbon Dioxide Equivalent (CO_2e): 7,898.655
Total Energy Consumption (TEC): 102.929