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 building regressions to predict relationships between traffic conditions and emissions can be found in the accompanying documentation of emissions modeling details.

Electronic Open-Road Tolling Tool

Converting tolling plazas to electronic open-road tolling (EORT) facilities smooths drive cycles and reduces emissions. EORT gantries are mounted with vehicle-to-infrastructure (V2I) technologies—such as high-resolution cameras for license plate reading and high-speed sensors for transponder detection—which eliminate idling, braking, and rapid acceleration in the tolling area. Other benefits of EORT include alleviation of traffic congestion, improved safety, lower asset management and maintenance costs, and the ability to implement instantaneous fare changes for variable or congestion pricing.

Two scenarios are presented in this tool. The first scenario is conversion to EORT from a full stop (either human- or machine-operated) toll plaza with vehicle queuing and idling. The second scenario is conversion to EORT from a toll plaza where vehicles with transponders pass through at a 10–15 mph rolling cruise. In both cases, the EORT facility results in free flow or near free flow conditions.

This document is organized into three sections—User Guide, Tool Methodology, and Examples—to aid the user in selecting inputs and interpreting results from the emissions calculator tool. The User Guide provides definitions of user inputs and tool outputs and direction on how to properly input values into the tool. The Tool Methodology section outlines the steps and equations executed within the tool to calculate emission reductions. This section also notes any assumptions incorporated in the tool. The Examples section describes how to use the tool for project analysis.

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USER GUIDE

This section describes each user input and tool output as well as error messages and key assumptions present in the tool.

User Inputs

This Electronic Tolling Tool 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 EORT tolling conversion project type (either full stop to free flow or rolling cruise to free flow). The user-defined inputs are described in Table 1 .

Table 1 . User Inputs

Item	User Input	Units	Description
(1)	Project evaluation year	-----	Use the drop-down menu to choose a year between 2020 and 2030.
(2)	Tolling facility conversion type	-----	Use the drop-down menu to choose the specific tolling conversion project.
(3a)	Toll throughput	veh/ln/hr	Enter the average hourly toll throughput (in vehicles per toll lane per hour) before and after conversion.
(3b)	Speed	mph	Enter the average speed across the entire tolling facility (i.e. for the pre-conversion scenarios, from deceleration from highway speed when approaching the toll to acceleration back to highway speed after exiting the toll) before and after facility conversion.
(3c)	Truck traffic	%	Enter the percentage of truck (and other heavy-duty) traffic out of total hourly toll throughput before and after conversion.
(4a)	Toll lanes	----	Enter the number of toll lanes before and after facility conversion.
(4b)	Representative operating hours	hr/day	Enter the number of hours per day that the tolling facility operates under the traffic conditions described in Question 3 before and after conversion.
(5)	Facility length	mi	Enter the total length of facility between the toll approach and exit (in miles).

Toll throughput and average speed data may be either modeled or measured. If available, measurements from traffic counters, video footage, or other roadside sensors provide the most accurate traffic condition estimates. When measurements are not readily available, traffic conditions can be estimated using travel demand models or traffic microsimulations. If necessary, average speeds can also be obtained either from traffic sensors or the posted speed limit.

This tool only models emissions that occur during the representative operating hours for the tolling facility. To calculate emissions reductions under different traffic conditions, users will need to conduct a separate analysis, as shown later in the Examples section. Users looking to calculate daily emission reductions can follow the methodology in Example 4 to run the tool under peak, non-peak, and overnight conditions and then take the sum of the results across those varying conditions.

Tool Outputs

Outputs of this tool include changes to network performance and emissions reductions. These outputs will not automatically update when inputs are changed The 'Calculate Output' button must be clicked again to recalculate the results. If you would like to return to default settings and clear all inputs, click on the 'Reset to Default Values' button at the top right of the interface.

For network performance outputs, the tool calculates the change in average speed, estimated travel time, total hourly traffic throughput, and traffic density resulting from the tolling facility conversion. For emissions outputs, the tool calculates emissions reductions for five pollutants—carbon monoxide (CO), particulate matter with diameters < 2.5 Âµm (PM2.5), particulate matter with diameters < 10 Âµm (PM10), nitrogen oxides (NOx), and volatile organic compounds (VOC) —in kilograms per day (kg/day) for CMAQ reporting. Reductions in carbon dioxide equivalents (CO2e) and total energy consumption (TEC) are also provided in in kg/day and millions of British Thermal Units per day (MMBTU/day), respectively. Note again that daily reductions will need to be aggregated across peak, non-peak, and overnight conditions. Emissions reductions represent the change in emissions resulting from the toll conversion project. Equations for changes in network performance and emissions reductions are described in detail in the Tool Methodology section.

For all pollutants, a positive emission reduction can be interpreted as a decrease in emissions (or a benefit) whereas a negative emissions reduction can be interpreted as an increase in emissions (or a disbenefit) resulting from the conversion project.

Error Messages

Table 2 below list error messages that the user may encounter in this tool, the reason for the error message, and the solution. Once you correct any errors, press 'Calculate Output' to recalculate the results.

Table 2 . Error Messages

Error Message	Reason for Error	Solution
Please input a year between 2020 and 2030 by using the drop-down menu.	Invalid input for project evaluation year.	Select a project evaluation year from the drop-down menu.
Please input a tolling conversion project type from the drop-down menu.	Invalid input for tolling conversion project type.	Select an electronic tolling conversion project from the drop-down menu.
This tool does not accept negative values.	The regression models only predict emissions benefits for non-negative input parameters.	Change any negative input values to non-negative values.
Please enter the average number of vehicles passing through a toll lane each hour.	Invalid input for toll throughput.	Enter the average toll throughput per lane per hour.
Please enter the average speed through the tolling facility.	Invalid input for toll speed.	Enter the average speed across all toll lanes in mph.
This tool is designed for conversions to open-road tolling that increase throughput and speed.	The average toll throughput and/or average speed decrease after facility conversion.	Change the toll throughput and/or toll speed so both values increase after facility conversion.
Please enter the percentage of heavy-duty traffic.	Invalid input for heavy-duty traffic.	Enter the percentage of heavy-duty traffic in terms of total toll throughput.
Please enter the number of toll lanes.	Invalid input for number of toll lanes.	Enter the number of lanes in the tolling facility.
This tool can only evaluate facilities with between two and twenty toll lanes.	Invalid input for number of toll lanes.	Adjust the number of toll lanes in the tolling facility.
Please enter the number of hours with similar tolling traffic conditions.	Invalid input for representative operating hours.	Enter the number of hours per day that the facility operates under the traffic conditions described.
Please enter the toll facility length.	Invalid input for toll facility length.	Enter the length between the toll approach and exit for the original facility.

Additionally, the tool provides warning messages for the following conditions which are either unrealistic or not yet tested:

- Toll throughputs above 750 veh/ln/hr before conversion and above 2,000 veh/ln/hr after conversion
- Average speeds above 60 mph before conversion and above 85 mph after conversion
- Heavy-duty traffic percentages above 25%
- Facilities with more than 20 toll lanes

TOOL METHODOLOGY

The following section describes how network performance changes and emissions reductions are calculated in the EORT tool. Additional details on the traffic microsimulations with the Simulation of Urban Mobility (SUMO), emission rate development with MOVES, and multivariable linear regression (MLR) predictions of emission results have been provided in accompanying documentation of the tool's emissions modeling. Other traffic microsimulation tools (such as Vissim, Synchro, or AIMSUN) can generate similar vehicle trajectories, SUMO was chosen for fast performance and ease-of-use.

Network Performance

The change in average speed in miles per hour (mph) is the difference in the user-inputted values for average speed (in mph) before versus average speed after conversion of the tolling facility as shown in Equation 1.

$$\Delta\, average\ speed = average\ speed_{after} - average\ speed_{before} \quad (1)$$

Travel time in minutes is calculated from the user inputs by dividing the tolling facility length (in miles) by the average speed (in mph) and applying the appropriate conversion factor. The change in travel time before versus after conversion of the tolling facility is described by Equation 2.

$$\Delta\, travel\ time = \left(\frac{facility\ length_{after}}{average\ speed_{after}} \times 60\frac{min}{hr}\right) - \left(\frac{facility\ length_{before}}{average\ speed_{before}} \times 60\frac{min}{hr}\right) \quad (2)$$

Total traffic hourly throughput in vehicles per hour (veh/hr) is calculated by multiplying the hourly throughput volume per toll lane (vehicles/lane/hour) by the total number of toll lanes. The change in total hourly traffic throughput before versus after conversion of the tolling facility is shown in Equation 3.

$$\Delta\, total\ traffic\ throughput\ volume = \left(throughput_{after} \times lanes_{after}\right) - \left(throughput_{before} \times lanes_{before}\right) \quad (3)$$

Lastly, traffic density in vehicles per mile (veh/mi) is calculated from the user-supplied average speed (in mph) and total hourly traffic throughput (in veh/hr) that is calculated within the tool and described above. Traffic density is the total hourly traffic throughput divided by the average speed. The change in traffic density before versus after conversion of the tolling facility is described in Equation 4.

$$\Delta\, traffic\ density = \left(\frac{throughput_{after} \times lanes_{after}}{average\ speed_{after}}\right) - \left(\frac{throughput_{after} \times lanes_{before}}{average\ speed_{before}}\right) \quad (4)$$

For all traffic conditions, a negative value can be interpreted as a decrease in the traffic condition parameter resulting from the conversion project. Positive values are interpreted as an increase in the traffic condition parameter post-conversion.

Emission Reductions

Traffic microsimulations of the various tolling facility types (full stop, rolling stop, free flow) were conducted using SUMO to estimate the change in driving behavior from the full stop or rolling cruise scenarios to free flow through electronic open-road tolling. Emissions data were obtained from hourly project-level MOVES runs with custom operating mode distributions derived from the vehicle trajectories simulated by SUMO. Using the SUMO and MOVES data, regressions were constructed to predict emissions rates per hour (kg/hr) for each pollutant based on evaluation year, traffic throughput, average speed, and truck traffic percentage. Please refer to the accompanying Emissions Modeling Document for further information on SUMO and MLR.

There were a total of 21 regression equations (3 scenarios x 7 pollutants), each containing 18 data points. All the MLR equations had strong goodness of fits (multiple R2 are 0.822–0.989), with the full stop scenario usually populating the lower R2 values of that range across different pollutants.

For each pollutant, the change in reported CMAQ emissions (kg/day) is the difference between the emissions rate before (pre-) versus after (post-) conversion of the tolling facility:

$$\Delta Emissions = Emissions_{pre} - Emissions_{post} \quad (5)$$

$$Emissions_{pre} = (k_{q_{scen,pol}} \cdot q_{pre} \cdot n_{lanes_{pre}} + k_{s_{scen,pol}} \cdot s_{pre} + k_{\alpha_{scen,pol}} \cdot \alpha_{pre} + k_{y_{scen,pol}} \cdot y + K_{scen,pol}) \cdot h_{pre} \cdot d$$

$$Emissions_{post} = (k_{q_{scen,pol}} \cdot q_{post} \cdot n_{lanes_{post}} + k_{s_{scen,pol}} \cdot s_{post} + k_{\alpha_{scen,pol}} \cdot \alpha_{post} + k_{y_{scen,pol}} \cdot y + K_{scen,pol}) \cdot h_{post} \cdot d$$

where

y = project evaluation year,

d = original tolling facility length in miles,

$k_{q_{scen,pol}}$ = 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_{pre} = user-supplied input for hourly toll throughput per lane (veh/ln/hr) before conversion,

$n_{lanes_{pre}}$ = number of toll lanes before conversion,

s_{pre} = user-supplied average speed through tolling facility (mph) before conversion,

a_{pre} = user-supplied input for percentage of heavy-duty vehicle traffic before conversion,

h_{pre} = representative hours per day with similar tolling traffic conditions before conversion,

q_{post} = user-supplied input for hourly toll throughput per lane (veh/ln/hr) after conversion,

$n_{lanes_{post}}$ = number of toll lanes after conversion,

s_{post} = user-supplied average speed through tolling facility (mph) after conversion,

a_{post} = user-supplied input for percentage of heavy-duty vehicle traffic after conversion, and

h_{post} = representative hours per day with similar tolling traffic conditions after conversion.

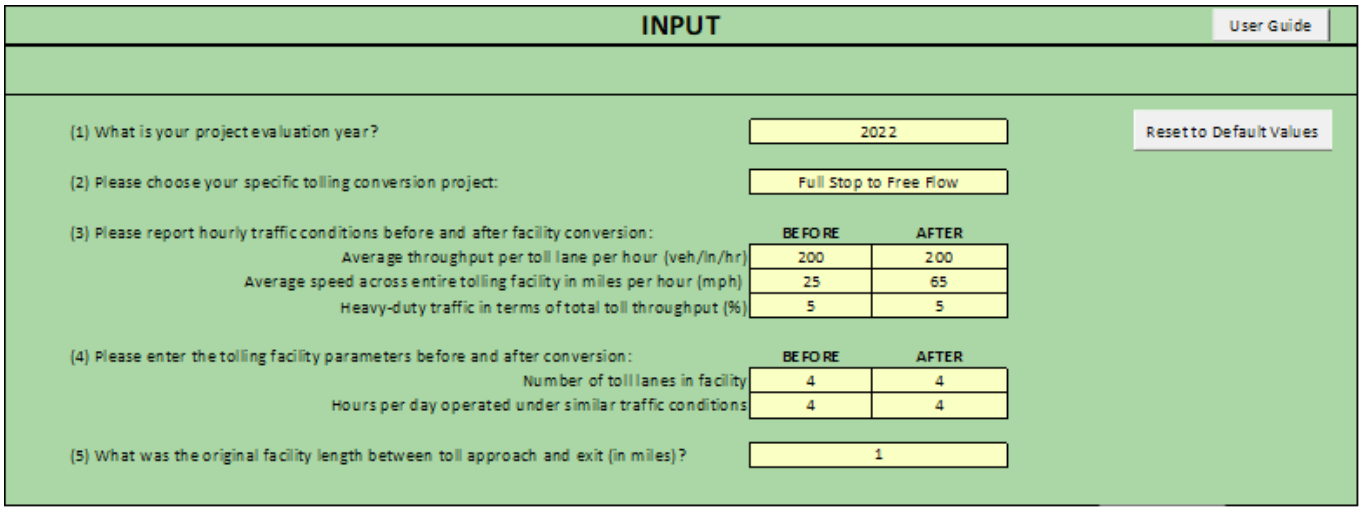
For more information on specific MLR correlations and predictive variable coefficients, please consult this tool's Emissions Modeling Document.

EXAMPLES

Example 1: Nearly Identical Pre- and Post-Traffic Conditions

A transportation agency plans to replace a human-operated tolling plaza with EORT gantries in 2022 to eliminate vehicle queuing. The tolling facility, which is currently 1 mi in length between the toll approach and exit, will have the same number of lanes (4) after conversion. From video footage, the agency knows that current toll throughput is 200 veh/ln/hr, with 5% of the throughput being heavy-duty vehicles. These traffic conditions will remain the same after facility conversion; however, average speed is expected to increase from 25 mph to 65 mph across all toll lanes. Additionally, the tolling facility operates under these traffic conditions for 4 hours per day before and after conversion.

Based on this proposed project description, the user would enter the following inputs:



INPUT

User Guide

(1) What is your project evaluation year? 2022

Reset to Default Values

(2) Please choose your specific tolling conversion project: Full Stop to Free Flow

(3) Please report hourly traffic conditions before and after facility conversion:

	BEFORE	AFTER
Average throughput per toll lane per hour (veh/ln/hr)	200	200
Average speed across entire tolling facility in miles per hour (mph)	25	65
Heavy-duty traffic in terms of total toll throughput (%)	5	5

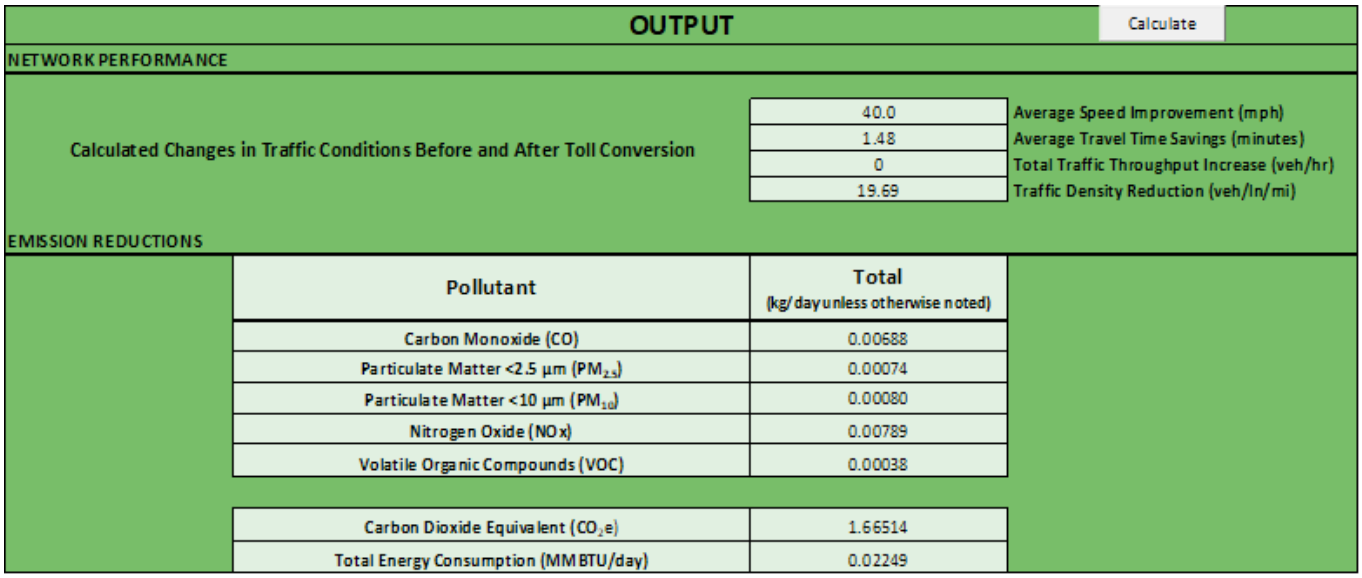
(4) Please enter the tolling facility parameters before and after conversion:

	BEFORE	AFTER
Number of toll lanes in facility	4	4
Hours per day operated under similar traffic conditions	4	4

(5) What was the original facility length between toll approach and exit (in miles)? 1

Project Evaluation Year: 2022
Tolling Conversion Project: Full Stop to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 200 (before), 200 (after)
Average Speed (mph): 25 (before), 65 (after)
Heavy-Duty Traffic (%): 5 (before), 5 (after)
Tolling Facility Parameters:
Number of Lanes: 4 (before), 4 (after)
Hours Operated (hr/day): 4 (before), 4 (after)
Original Facility Length: 1 mi

Once inputs are entered, click the 'Calculate Output' button to generate the following network performance and emission reduction results:



OUTPUT

Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion

40.0	Average Speed Improvement (mph)
1.48	Average Travel Time Savings (minutes)
0	Total Traffic Throughput Increase (veh/hr)
19.69	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

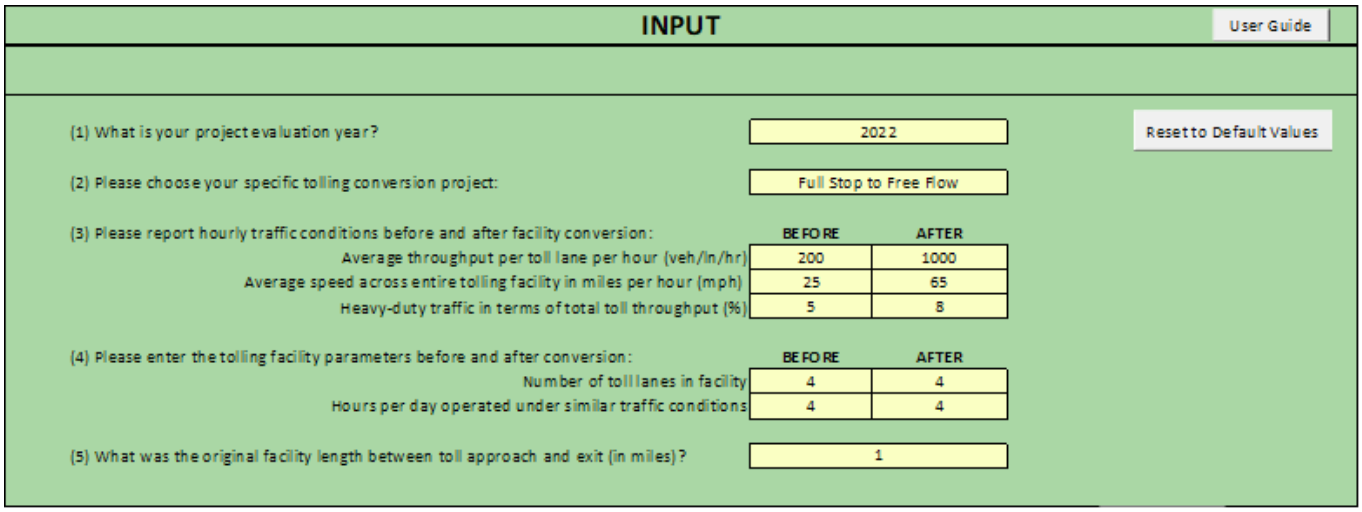
Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00688
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00074
Particulate Matter <10 µm (PM_{10})	0.00080
Nitrogen Oxide (NOx)	0.00789
Volatile Organic Compounds (VOC)	0.00038
Carbon Dioxide Equivalent (CO_2e)	1.66514
Total Energy Consumption (MMBTU/day)	0.02249

Changes in Network Performance
Average Speed Improvement (mph): 40.0
Average Travel Time Savings (min): 1.48
Total Traffic Throughput Increase (veh/hr): 0
Traffic Density Reduction (veh/ln/mi): 19.69
Emission Reductions (kg/day)
CO: 0.00688
PM2.5: 0.00074
PM10: 0.00080
NOx: 0.00789
VOC: 0.00038
CO2e: 1.66514
TEC (MMBTU/day): 0.02249

Example 2: Different Pre- and Post-Conversion Traffic Conditions

Similar to Example 1, a transportation agency plans to replace a human-operated tolling plaza with EORT gantries in 2022 to eliminate vehicle queuing. The tolling facility, which is currently 1 mi in length between the toll approach and exit, will have the same number of lanes (4) after conversion. From video footage, the agency knows that current toll throughput is 200 veh/ln/hr with 5% of the throughput being heavy-duty vehicles. In addition to increasing average speed from 25 mph to 65 mph, facility conversion is also expected to increase toll throughout to 1,000 veh/ln/hr and heavy-duty traffic to 8%. These traffic conditions will be representative of the tolling facility for 4 hrs/day before and after conversion.

Based on this proposed project description, the user would enter the following inputs:



INPUT

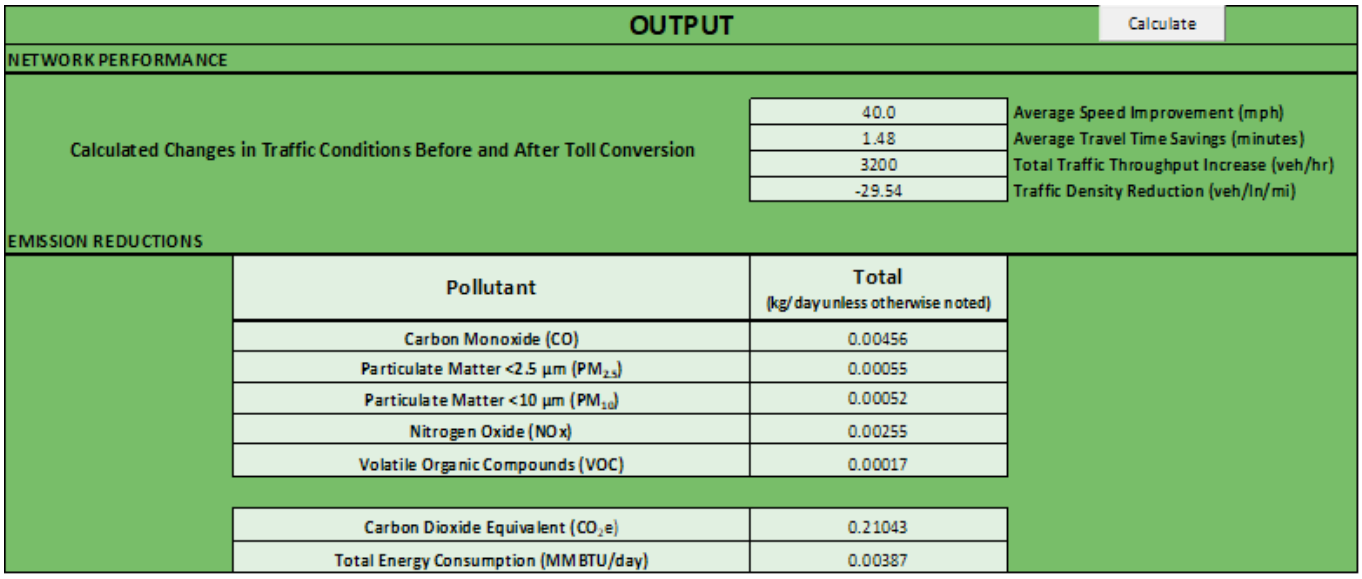
User Guide

Reset to Default Values

(1) What is your project evaluation year?	2022	
(2) Please choose your specific tolling conversion project:	Full Stop to Free Flow	
(3) Please report hourly traffic conditions before and after facility conversion:	BEFORE	AFTER
Average throughput per toll lane per hour (veh/ln/hr)	200	1000
Average speed across entire tolling facility in miles per hour (mph)	25	65
Heavy-duty traffic in terms of total toll throughput (%)	5	8
(4) Please enter the tolling facility parameters before and after conversion:	BEFORE	AFTER
Number of toll lanes in facility	4	4
Hours per day operated under similar traffic conditions	4	4
(5) What was the original facility length between toll approach and exit (in miles)?	1	

Project Evaluation Year: 2022
Tolling Conversion Project: Full Stop to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 200 (before), 1,000 (after)
Average Speed (mph): 25 (before), 65 (after)
Heavy-Duty Traffic (%): 5 (before), 8 (after)
Tolling Facility Parameters:
Number of Lanes: 4 (before), 4 (after)
Hours Operated (hr/day): 4 (before), 4 (after)
Original Facility Length: 1 mi

Once inputs are entered, click the 'Calculate Output' button to generation the following network performance and emissions reductions results:



OUTPUT

Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion	
40.0	Average Speed Improvement (mph)
1.48	Average Travel Time Savings (minutes)
3200	Total Traffic Throughput Increase (veh/hr)
-29.54	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00456
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00055
Particulate Matter <10 µm (PM_{10})	0.00052
Nitrogen Oxide (NOx)	0.00255
Volatile Organic Compounds (VOC)	0.00017
Carbon Dioxide Equivalent (CO_2e)	0.21043
Total Energy Consumption (MMBTU/day)	0.00387

Changes in Network Performance
Average Speed Improvement (mph): 40.0
Average Travel Time Savings (min): 1.48
Total Traffic Throughput Increase (veh/hr): 3,200
Traffic Density Reduction (veh/ln/mi): -29.54

Emission Reductions (kg/day)
CO: 0.00456
PM2.5: 0.00055
PM10: 0.00052
NOx: 0.00255
VOC: 0.00017
CO2e: 0.21043
TEC (MMBTU/day): 0.00387

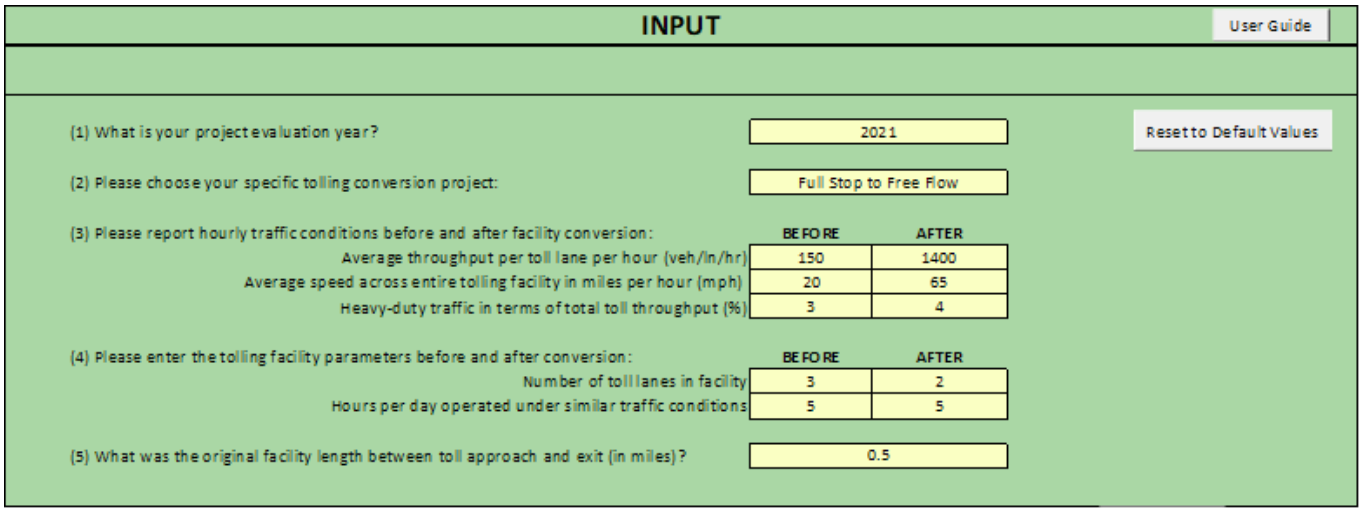
Example 3: Hybrid Pre-Conversion Tolling Facility

A transportation agency plans to replace a hybrid toll with EORT gantries in 2021 to reduce the need for braking and accelerating. The current tolling facility has 6 toll lanes and a length of 0.5 mi between the toll approach and exit. Three of the lanes are human-operated, full stop toll lanes whereas the other three lanes are E-ZPass, rolling cruise toll lanes. One of the full stop lanes and one of the rolling cruise lanes will be removed during conversion, so the tolling facility will only have 4 toll lanes after conversion. Based on traffic demand models, the agency estimates current toll throughput to be 150 veh/ln/hr on the full stop lanes and 300 veh/ln/hr on the rolling cruise lanes, average speed to be 20 mph on the full stop lanes and 30 mph on the rolling cruise lanes, and heavy-duty traffic to be 3% on all lanes. This toll conversion project is anticipated to increase toll throughput to 1,400 veh/ln/hr, heavy-duty traffic to 4%, and average speeds to 65 mph on all lanes. All traffic conditions are representative of the tolling facility for 5 hrs/day before and after conversion.

To estimate emission reductions from this hybrid pre-conversion scenario, the user will need to conduct separate analyses for the full stop and rolling cruise pre-conversion lanes.

FULL STOP LANES

Based on the proposed project for the full stop lanes, the user would enter the following inputs:



Project Evaluation Year: 2021
Tolling Conversion Project: Full Stop to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 150 (before), 1,400 (after)
Average Speed (mph): 20 (before), 65 (after)
Heavy-Duty Traffic (%): 3 (before), 4 (after)
Tolling Facility Parameters:
Number of Lanes: 3 (before), 2 (after)
Hours Operated (hr/day): 5 (before), 5 (after)
Original Facility Length: 0.5 mi

Once inputs are entered, click the 'Calculate Output' button to generate the following network performance and emission reduction results:

OUTPUT Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion

45.0	Average Speed Improvement (mph)
1.04	Average Travel Time Savings (minutes)
2350	Total Traffic Throughput Increase (veh/hr)
-20.58	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00446
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00026
Particulate Matter <10 µm (PM_{10})	0.00030
Nitrogen Oxide (NOx)	0.00306
Volatile Organic Compounds (VOC)	0.00019
Carbon Dioxide Equivalent (CO_2e)	0.72913
Total Energy Consumption (MMBTU/day)	0.00980

Changes in Network Performance
Average Speed Improvement (mph): 45.0
Average Travel Time Savings (min): 1.04
Total Traffic Throughput Increase (veh/hr): 2,350
Traffic Density Reduction (veh/ln/mi): -20.58
Emission Reductions (kg/d)
CO: 0.00446
PM2.5: 0.00026
PM10: 0.00030
NOx: 0.00306
VOC: 0.00019
CO2e: 0.72913
TEC (MMBTU/day): 0.00980

ROLLING CRUISE LANES

Based on the proposed project for the rolling cruise lanes, the user would enter the following inputs:

INPUT User Guide

Reset to Default Values

(1) What is your project evaluation year?	2021
(2) Please choose your specific tolling conversion project:	Rolling Cruise to Free Flow

(3) Please report hourly traffic conditions before and after facility conversion:

	BEFORE	AFTER
Average throughput per toll lane per hour (veh/ln/hr)	300	1400
Average speed across entire tolling facility in miles per hour (mph)	30	65
Heavy-duty traffic in terms of total toll throughput (%)	3	4

(4) Please enter the tolling facility parameters before and after conversion:

	BEFORE	AFTER
Number of toll lanes in facility	3	2
Hours per day operated under similar traffic conditions	5	5

(5) What was the original facility length between toll approach and exit (in miles)? 0.5

Project Evaluation Year: 2021
Tolling Conversion Project: Rolling Cruise to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 300 (before), 1,400 (after)
Average Speed (mph): 30 (before), 65 (after)
Heavy-Duty Traffic (%): 3 (before), 4 (after)
Tolling Facility Parameters:
Number of Lanes: 3 (before), 2 (after)
Hours Operated (hr/day): 5 (before), 5 (after)
Original Facility Length: 0.5 mi

Once inputs are entered, click the 'Calculate Output' button to generate the following network performance and emission reduction results:

OUTPUT Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion	
35.0	Average Speed Improvement (mph)
0.54	Average Travel Time Savings (minutes)
1900	Total Traffic Throughput Increase (veh/hr)
-13.08	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00093
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00005
Particulate Matter <10 µm (PM_{10})	0.00017
Nitrogen Oxide (NOx)	0.00018
Volatile Organic Compounds (VOC)	0.00009
Carbon Dioxide Equivalent (CO_2e)	-0.08390
Total Energy Consumption (MMBTU/day)	-0.00097

Changes in Network Performance
Average Speed Improvement (mph): 35.0
Average Travel Time Savings (min): 0.54
Total Traffic Throughput Increase (veh/hr): 1,900
Traffic Density Reduction (veh/ln/mi): -13.08
Emission Reductions (kg/day)
CO: 0.00093
PM2.5: 0.00005
PM10: 0.00017
NOx: 0.00018
VOC: 0.00009
CO2e: -0.08390
TEC (MMBTU/day): -0.00097

OVERALL BENEFITS

The table below summarizes the emissions reductions from converting the full stop and rolling cruise lanes. Overall benefits are then calculated by adding the results from each separate analysis as shown in the sample calculation below.

Pollutant	Full Stop	Rolling Stop	OVERALL
CO (kg/day)	0.00446	0.00093	0.00539
PM2.5 (kg/day)	0.00026	0.00005	0.00031
PM10 (kg/day)	0.00030	0.00017	0.00047
NOx (kg/day)	0.00306	0.00018	0.00324
VOC (kg/day)	0.00019	0.00009	0.00028
CO2e (kg/day)	0.72913	-0.08390	0.64523
TEC (MMBTU/day)	0.00980	-0.00097	0.00883

Sample Calculation:

$$Total\ CO\ \left(\frac{kg}{d}\right) = 0.00446\frac{kg}{d} + 0.00093\frac{kg}{d} = 0.00539\frac{kg}{d}$$

Example 4: Determining Daily Emission Reductions

A transportation agency plans to replace a low-speed toll with EORT gantries in 2021 to reduce vehicle collisions around the existing tolling facility. The current tolling facility, which has a length of 0.5 mi between the toll

approach and exit, will still have 5 toll lanes after conversion. The transportation agency would like to estimate daily emission reductions from this rolling cruise conversion.

During peak hours, which last 4 hr/day before and after conversion, the current toll throughput is 350 veh/ln/hr with 3% heavy-duty traffic and average speeds of 15 mph according to video footage. The conversion project is anticipated to increase toll throughput to 1,500 veh/ln/hr, heavy-duty traffic to 5%, and average speeds to 60 mph.

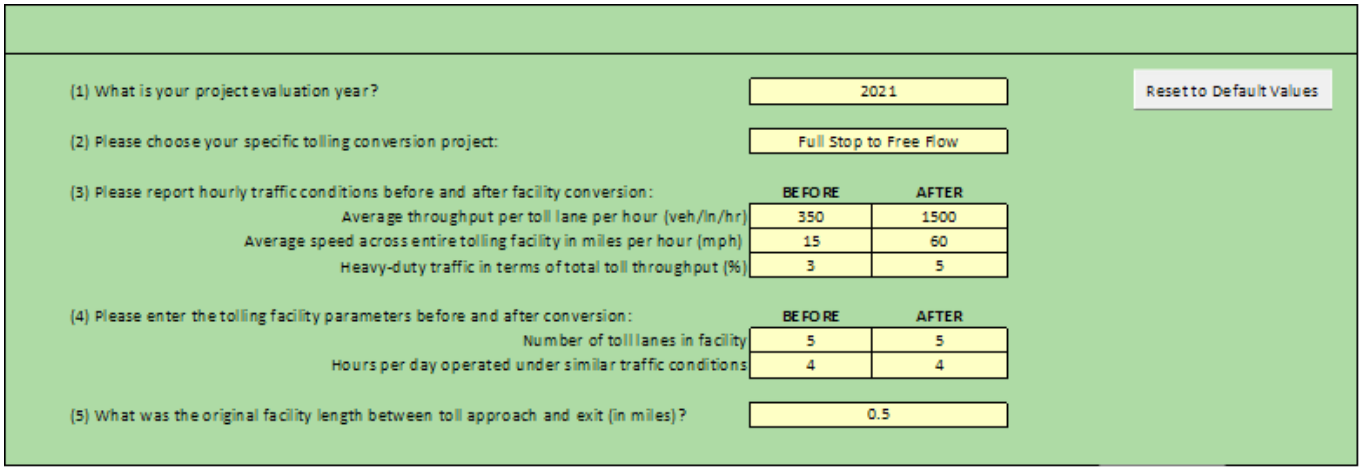
During non-peak hours, which last 10 hr/day before and after conversion, the current toll throughput is 200 veh/ln/hr with 25 mph average speeds according to video footage. The conversion project is anticipated to increase toll throughput to 600 veh/ln/hr and average speeds to 60 mph. Heavy-duty traffic is expected to remain at 2% before and after conversion.

Lastly, during overnight hours, which last 10 hr/day before and after conversion, the current toll throughput is 150 veh/ln/hr with 4% heavy-duty traffic and average speeds of 30 mph according to video footage. The conversion project is anticipated to increase toll throughput to 200 veh/ln/hr, heavy-duty traffic to 6%, and average speeds to 65 mph.

To estimate daily emission reductions, the user will need to conduct three separate analyses.

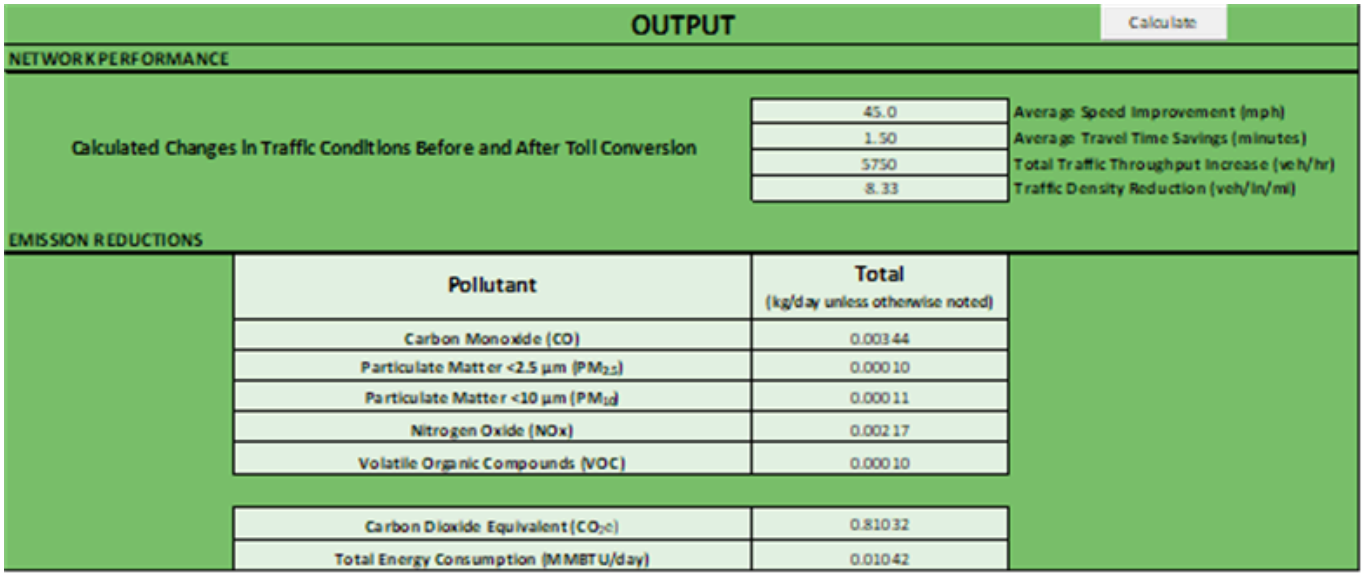
PEAK HOURS

Based on the peak hour scenario described, the user would enter the following inputs:



Project Evaluation Year: 2021
Tolling Conversion Project: Full Stop to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 350 (before), 1,500 (after)
Average Speed (mph): 15 (before), 60 (after)
Heavy-Duty Traffic (%): 3 (before), 5 (after)
Tolling Facility Parameters:
Number of Lanes: 5 (before), 5 (after)
Hours Operated (hr/day): 4 (before), 4 (after)
Original Facility Length: 0.5 mi

Once inputs are entered, click the 'Calculate Output' button to generate the following network performance and emission reduction results during peak hours:



OUTPUT Calculate

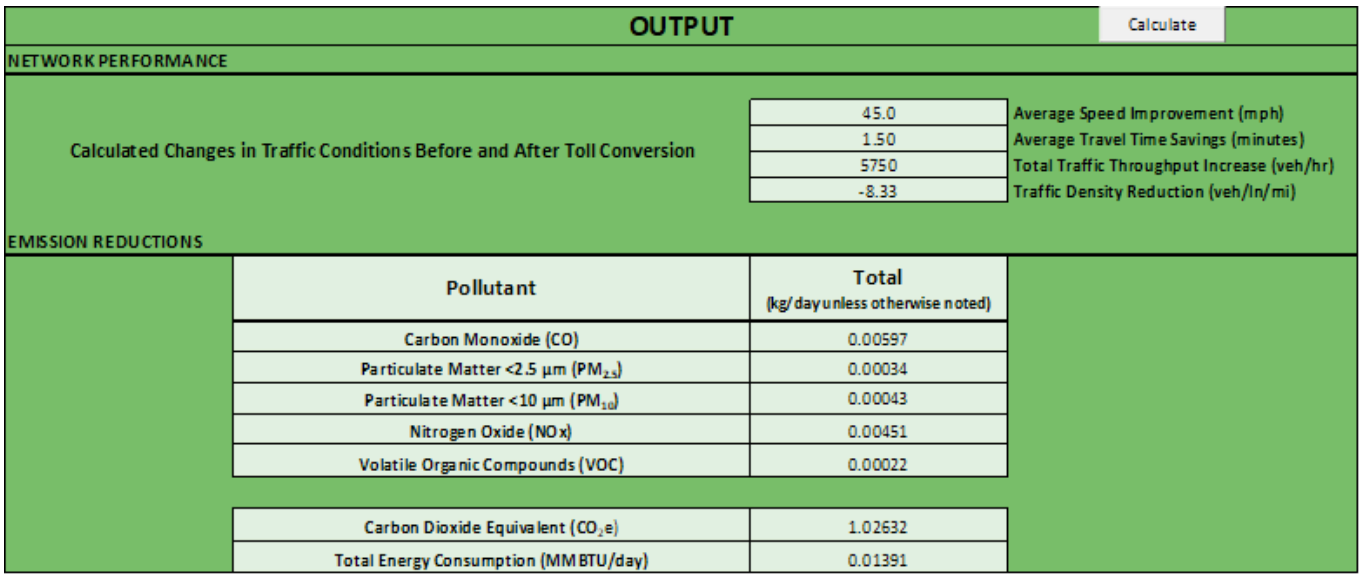
NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion

45.0	Average Speed Improvement (mph)
1.50	Average Travel Time Savings (minutes)
5750	Total Traffic Throughput Increase (veh/hr)
8.33	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00344
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00010
Particulate Matter <10 µm (PM_{10})	0.00011
Nitrogen Oxide (NOx)	0.00217
Volatile Organic Compounds (VOC)	0.00010
Carbon Dioxide Equivalent (CO_2e)	0.81032
Total Energy Consumption (MMBTU/day)	0.01042



OUTPUT Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion

45.0	Average Speed Improvement (mph)
1.50	Average Travel Time Savings (minutes)
5750	Total Traffic Throughput Increase (veh/hr)
-8.33	Traffic Density Reduction (veh/ln/mi)

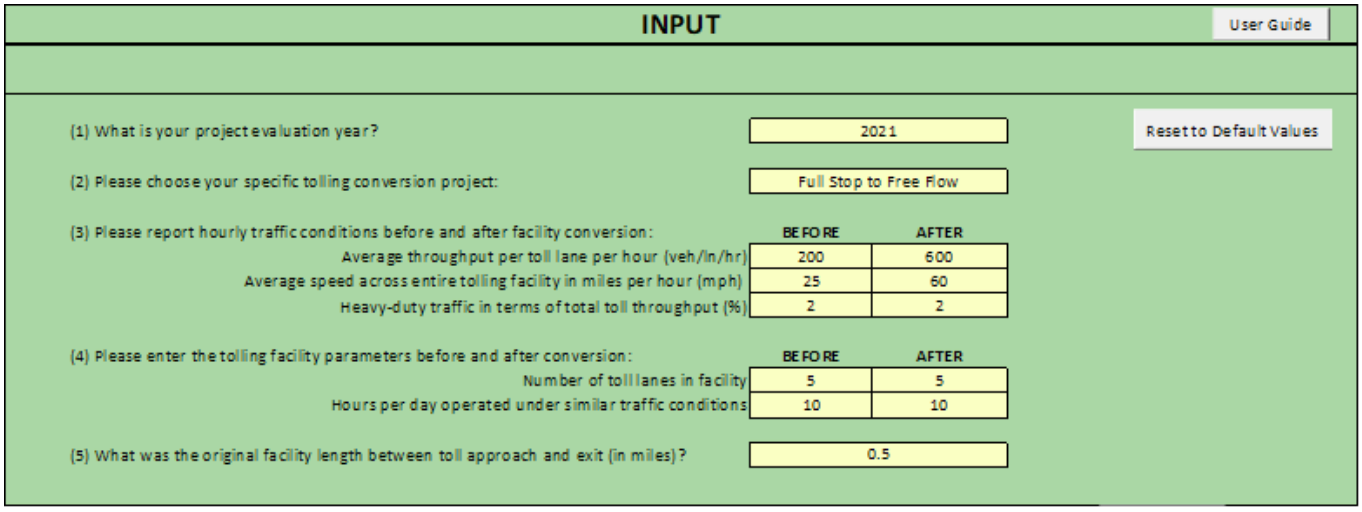
EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00597
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00034
Particulate Matter <10 µm (PM_{10})	0.00043
Nitrogen Oxide (NOx)	0.00451
Volatile Organic Compounds (VOC)	0.00022
Carbon Dioxide Equivalent (CO_2e)	1.02632
Total Energy Consumption (MMBTU/day)	0.01391

Changes in Network Performance
Average Speed Improvement (mph): 45.0
Average Travel Time Savings (min): 1.50
Total Traffic Throughput Increase (veh/hr): 5,750
Traffic Density Reduction (veh/ln/mi): -8.33
Emission Reductions (kg/d)
CO: 0.00597
PM2.5: 0.00034
PM10: 0.00043
NOx: 0.00451
VOC: 0.00022
CO2e: 1.02632
TEC (MMBTU/day): 0.01391

NON-PEAK HOURS

Based on the non-peak hour scenario described, the user would enter the following inputs:



INPUT

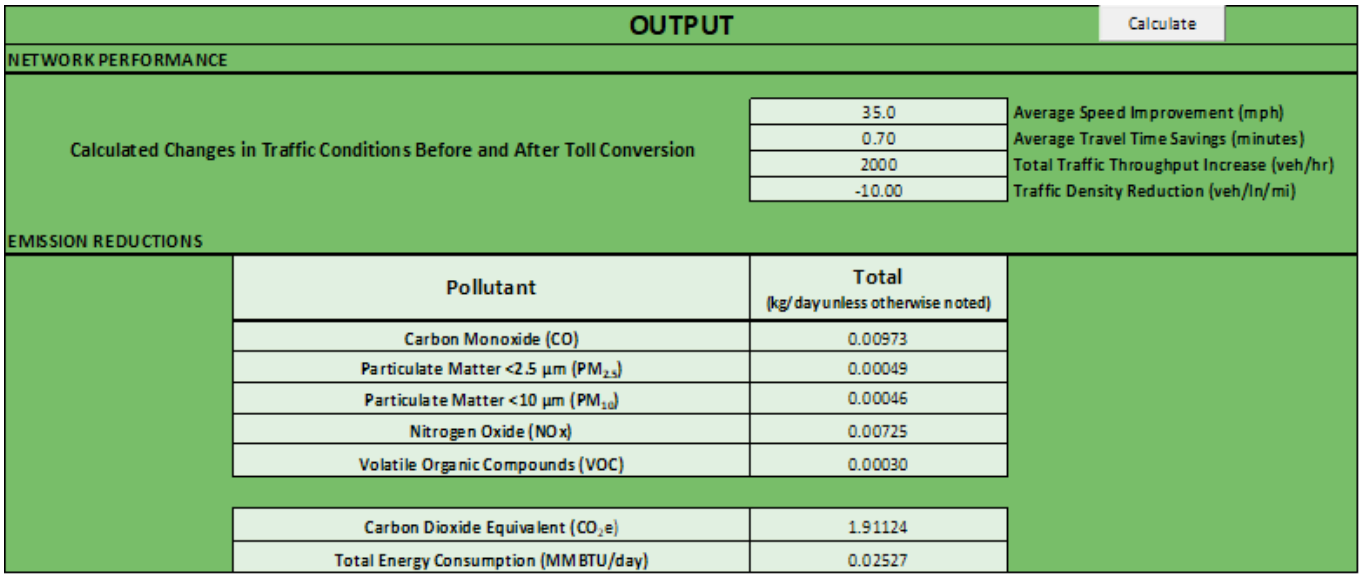
User Guide

Reset to Default Values

(1) What is your project evaluation year?	2021	
(2) Please choose your specific tolling conversion project:	Full Stop to Free Flow	
(3) Please report hourly traffic conditions before and after facility conversion:	BEFORE	AFTER
Average throughput per toll lane per hour (veh/ln/hr)	200	600
Average speed across entire tolling facility in miles per hour (mph)	25	60
Heavy-duty traffic in terms of total toll throughput (%)	2	2
(4) Please enter the tolling facility parameters before and after conversion:	BEFORE	AFTER
Number of toll lanes in facility	5	5
Hours per day operated under similar traffic conditions	10	10
(5) What was the original facility length between toll approach and exit (in miles)?	0.5	

Project Evaluation Year: 2021
Tolling Conversion Project: Full Stop to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 200 (before), 600 (after)
Average Speed (mph): 25 (before), 60 (after)
Heavy-Duty Traffic (%): 2 (before), 2 (after)
Tolling Facility Parameters:
Number of Lanes: 5 (before), 5 (after)
Hours Operated (hr/day): 10 (before), 10 (after)
Original Facility Length: 0.5 mi

Once inputs are entered, click the 'Calculate Output' button to generation the following network performance and emission reduction results during non-peak hours:



OUTPUT

Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion	
35.0	Average Speed Improvement (mph)
0.70	Average Travel Time Savings (minutes)
2000	Total Traffic Throughput Increase (veh/hr)
-10.00	Traffic Density Reduction (veh/ln/mi)

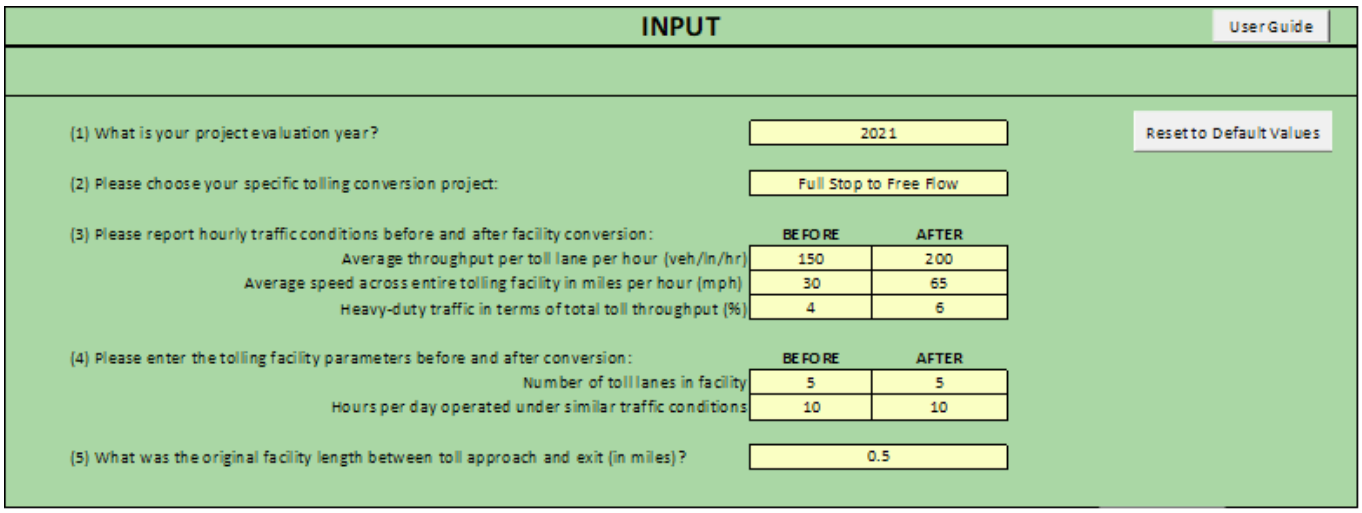
EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00973
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00049
Particulate Matter <10 µm (PM_{10})	0.00046
Nitrogen Oxide (NOx)	0.00725
Volatile Organic Compounds (VOC)	0.00030
Carbon Dioxide Equivalent (CO_2e)	1.91124
Total Energy Consumption (MMBTU/day)	0.02527

Changes in Network Performance
Average Speed Improvement (mph): 35.0
Average Travel Time Savings (min): 0.70
Total Traffic Throughput Increase (veh/hr): 2,000
Traffic Density Reduction (veh/ln/mi): -10.00
Emission Reductions (kg/d)
CO: 0.00973
PM2.5: 0.00049
PM10: 0.00046
NOx: 0.00725
VOC: 0.00030
CO2e: 1.91124
TEC (MMBTU/day): 0.02527

OVERNIGHT HOURS

Based on the overnight scenario described, the user would enter the following inputs:



INPUT — User Guide

(1) What is your project evaluation year?	2021	Reset to Default Values
(2) Please choose your specific tolling conversion project:	Full Stop to Free Flow	

(3) Please report hourly traffic conditions before and after facility conversion:

	BEFORE	AFTER
Average throughput per toll lane per hour (veh/ln/hr)	150	200
Average speed across entire tolling facility in miles per hour (mph)	30	65
Heavy-duty traffic in terms of total toll throughput (%)	4	6

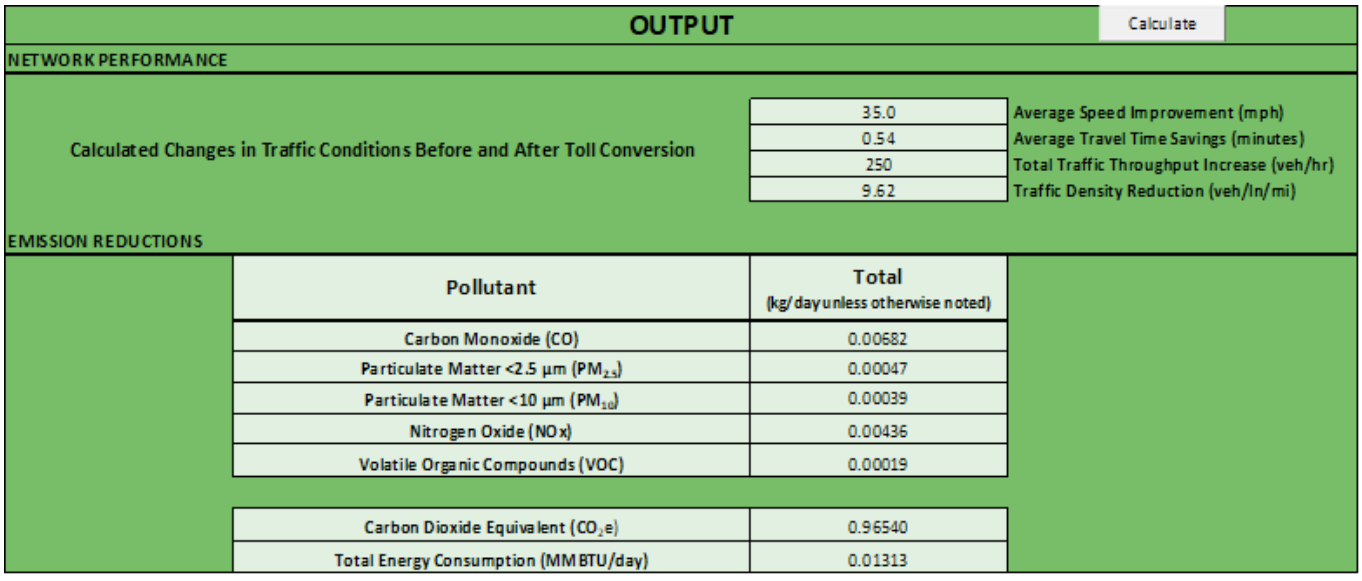
(4) Please enter the tolling facility parameters before and after conversion:

	BEFORE	AFTER
Number of toll lanes in facility	5	5
Hours per day operated under similar traffic conditions	10	10

(5) What was the original facility length between toll approach and exit (in miles)? 0.5

Project Evaluation Year: 2021
Tolling Conversion Project: Full Stop to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 150 (before), 200 (after)
Average Speed (mph): 30 (before), 65 (after)
Heavy-Duty Traffic (%): 4 (before), 6 (after)
Tolling Facility Parameters:
Number of Lanes: 5 (before), 5 (after)
Hours Operated (hr/day): 10 (before), 10 (after)
Original Facility Length: 0.5 mi

Once inputs are entered, click the 'Calculate Output' button to generation the following network performance and emission reduction results during non-peak hours:



OUTPUT — Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion	
35.0	Average Speed Improvement (mph)
0.54	Average Travel Time Savings (minutes)
250	Total Traffic Throughput Increase (veh/hr)
9.62	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00682
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00047
Particulate Matter <10 µm (PM_{10})	0.00039
Nitrogen Oxide (NOx)	0.00436
Volatile Organic Compounds (VOC)	0.00019
Carbon Dioxide Equivalent (CO_2e)	0.96540
Total Energy Consumption (MMBTU/day)	0.01313

Changes in Network Performance
Average Speed Improvement (mph): 35.0
Average Travel Time Savings (min): 0.54
Total Traffic Throughput Increase (veh/hr): 250
Traffic Density Reduction (veh/ln/mi): 9.62
Emission Reductions (kg/d)
CO: 0.00682
PM2.5: 0.00047
PM10: 0.00039
NOx: 0.00436
VOC: 0.00019
CO2e: 0.96540
TEC (MMBTU/day): 0.01313

DAILY BENEFITS

The table below summarizes the emissions reductions during peak, non-peak, and overnight hours. Daily benefits are then calculated using a weighted summation of the results from each separate analysis as shown in the sample calculation below.

Pollutant	Peak (4 hr/day)	Non-Peak (10 hr/day)	Overnight (10 hr/day)	DAILY (24 hr/day)
CO (kg/day)	0.00597	0.00973	0.00682	0.07554
PM2.5 (kg/day)	0.00034	0.00049	0.00047	0.00434
PM10 (kg/day)	0.00043	0.00046	0.00039	0.00462
NOx (kg/day)	0.00451	0.00725	0.00436	0.05492
VOC (kg/day)	0.00022	0.00030	0.00019	0.00250
CO2e (kg/day)	1.02632	1.91124	0.96540	13.06186
TEC (MMBTU/day)	0.01391	0.02527	0.01313	0.17562

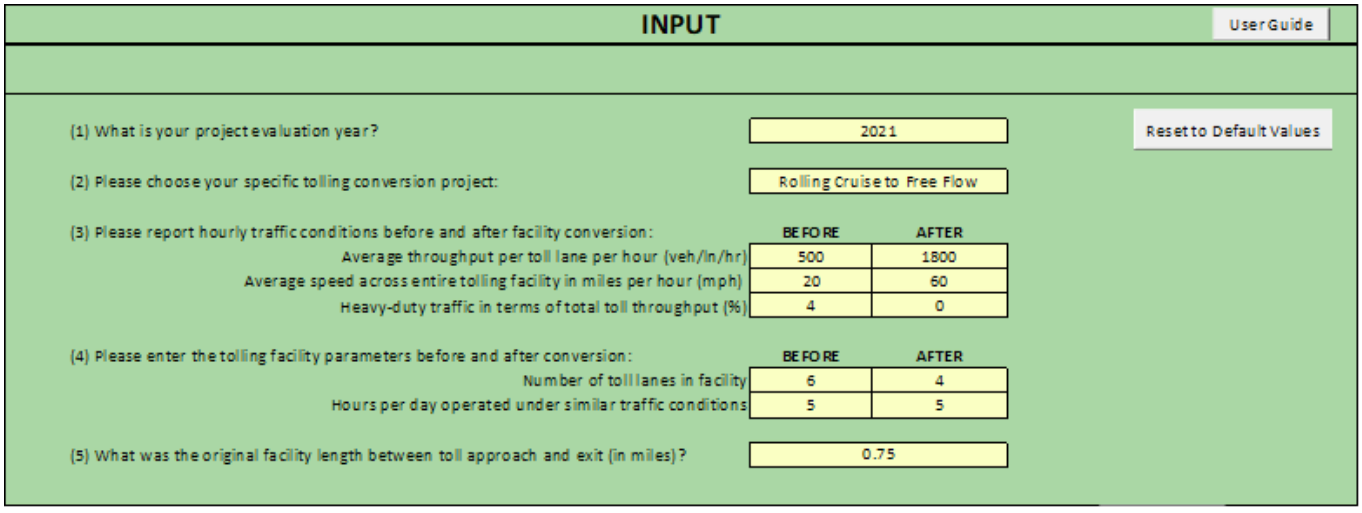
Sample Calculation:

$$Daily\ CO\ \left(\frac{kg}{day}\right) = \left[\left(0.00597\,\frac{kg}{day} \times \frac{1\ day}{4\ hr}\right) + \left(0.00973\,\frac{kg}{day} \times \frac{1\ day}{10\ hr}\right) + \left(0.00682\,\frac{kg}{day} \times \frac{1\ day}{10\ hr}\right)\right] \times \frac{24\ hr}{day} = 0.07554\,\frac{kg}{day}$$

Example 5: Heavy-Duty Traffic Ban

A transportation agency plans to replace a rolling stop tolling plaza with EORT gantries in 2021 to eliminate vehicle idling and queuing. The current tolling facility has 6 toll lanes and a length of 0.75 mi between the toll approach and exit. After conversion, the tolling facility will only have 4 toll lanes. Based on travel demand models, the agency estimates current toll throughput to be 500 veh/ln/hr with 4% heavy-duty traffic and 20 mph average speeds. The conversion project is anticipated to increase toll throughput to 1,800 veh/ln/hr and average speeds to 60 mph. Additionally, a heavy-duty traffic ban will be implemented during peak hours following conversion of the facility. All traffic conditions are representative of the tolling facility for 5 hr/day before and after conversion.

Based on this proposed project description, the user would enter the following inputs:



Project Evaluation Year: 2021
Tolling Conversion Project: Rolling Cruise to Free Flow
Hourly Traffic Conditions:
Average Toll Throughput (veh/ln/hr): 500 (before), 1,800 (after)
Average Speed (mph): 20 (before), 60 (after)

Heavy-Duty Traffic (%): 4 (before), 0 (after)
Tolling Facility Parameters:
Number of Lanes: 6 (before), 4 (after)
Hours Operated (hr/day): 5 (before), 5 (after)
Original Facility Length: 0.75 mi

Once inputs are entered, click the 'Calculate Output' button to generation the following network performance and emission reduction results:

OUTPUT Calculate

NETWORK PERFORMANCE

Calculated Changes in Traffic Conditions Before and After Toll Conversion	
40.0	Average Speed Improvement (mph)
1.50	Average Travel Time Savings (minutes)
4200	Total Traffic Throughput Increase (veh/hr)
30.00	Traffic Density Reduction (veh/ln/mi)

EMISSION REDUCTIONS

Pollutant	Total (kg/day unless otherwise noted)
Carbon Monoxide (CO)	0.00258
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.00037
Particulate Matter <10 µm (PM_{10})	0.00091
Nitrogen Oxide (NOx)	0.00664
Volatile Organic Compounds (VOC)	0.00057
Carbon Dioxide Equivalent (CO_2e)	1.36023
Total Energy Consumption (MMBTU/day)	0.01771

Changes in Network Performance
Average Speed Improvement (mph): 40.0
Average Travel Time Savings (min): 1.50
Total Traffic Throughput Increase (veh/hr): 4,200
Traffic Density Reduction (veh/ln/mi): 30.00
Emission Reductions (kg/d)
CO: 0.00258
PM2.5: 0.00037
PM10: 0.00091
NOx: 0.00664
VOC: 0.00057
CO2e: 1.36023
TEC (MMBTU/day): 0.01771

Appendix - Example Tolling Conversion Projects

This CMAQ tool highlights two possible tolling conversion cases: 1) from full stop to free flow, and 2) from rolling cruise to free flow. Both cases convert a toll plaza to an open-road tolling system with an overhead gantry equipped with radio signal receivers for vehicle-to-infrastructure (V2I) communications via in-vehicle electronic transponders and/or high-resolution cameras to capture license plate numbers for payment.

The full stop scenario usually involves a tolling facility with a human operator or machine operation, such as a toll gate lifted by an electronic transponder, a ticket taken by the driver, or a toll paid via a coin basket. The rolling cruise scenario is similar but typically does not have a toll gate; however, it still detects a V2I signal via electronic transponder, allowing vehicles to pass through at relatively low speeds (10-15 mph). The free flow scenario implements open-road tolling though an overhead gantry, enabling vehicles to pay the toll electronically without needing to brake from highway speed.

Figure 1a shows an example ungated toll plaza on the Massachusetts Turnpike (Interstate 90) in Allston, an outlying neighborhood of Boston, demonstrating the rolling cruise scenario, while Figure 1b shows the same highway location after completion of the tolling conversion. The new overhead gantry was placed about a half mile away – a tolling location no longer in the middle of an interchange. This eliminated the need for toll booths on several ramps entering or exiting the interchange, and was part of a larger network of EORT gantries placed strategically along I-90 by the Massachusetts Department of Transportation (MassDOT) to incorporate all movements to and from the facility and equitably charge users for the total distance traveled.

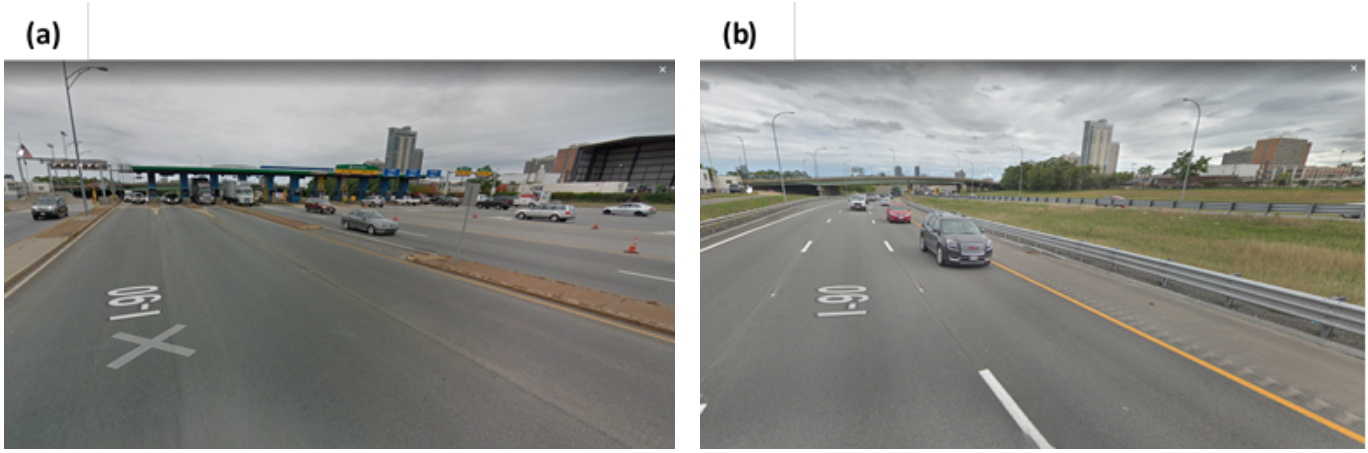


Figure 1. (a) Example highway site of toll plaza before EORT conversion to electronic open-road tolling (July 2011), and (b) site after conversion (Sept. 2018) on the Massachusetts Turnpike (Interstate 90) in Allston near Boston (courtesy of Google Maps)

The new EORT gantry on the Massachusetts Turnpike (I-90) in Allston is shown in Figure 2. Since construction in 2016, this EORT facility has reduced congestion and increased speeds on I-90. Based on a weekday sample of average speeds from INRIX data provided by MassDOT, speeds during peak commuting hours improved in 2017 and 2018 after tolling conversion compared to 2014 and 2015 before conversion (see Figure 3). During non-peak times, traffic maintained free flow or near free flow.

Figure 2. Example of an open-road tolling facility after construction of the overhead gantry (Oct. 2018) on the Massachusetts Turnpike (I-90) in Allston near Boston with a Google Maps inset of the approximate tolling location marked by the yellow figurine in the southeast corner.

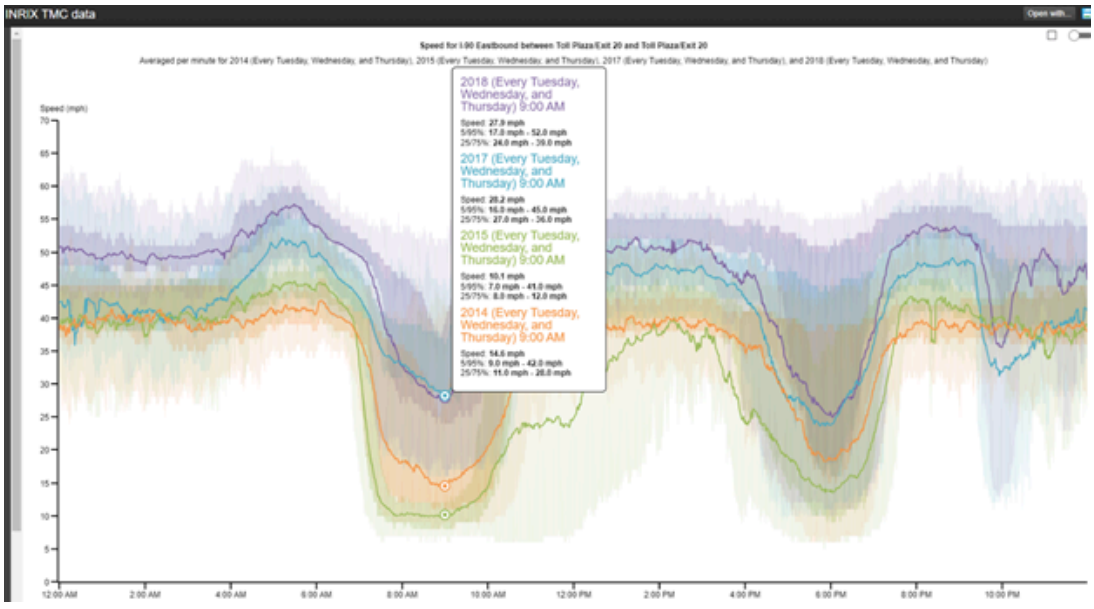


Figure 3. Aggregated midweek traffic speeds from 2014 to 2018 on Massachusetts Turnpike (I-90) at the tolling facility location in Allston near Boston before and after EORT conversion in 2016 (courtesy of INRIX/MassDOT)

Traffic microsimulations were built using SUMO software to represent the three different tolling scenarios listed earlier: full stop, rolling cruise, and free flow. To showcase how these tolling scenarios varied, second-by-second speed trajectories of the same five vehicles (with distinct vehicleIDs ranging 468-472) were plotted as they passed through the tolling area for each scenario.

Below, Figure 4 shows representative driving behavior of the first scenario before tolling conversion, where vehicles brake to a full stop from highway speed, briefly idle at the toll, and then accelerate back to highway speed. Figure 5 shows representative behavior of the second scenario before tolling conversion, where vehicles brake from highway speed to approximately 15 mph, maintain a rolling cruise through the toll, and the accelerate back to highway speed. Figure 6 shows representative behavior of the third and final scenario after tolling conversion, where vehicles maintain free flow on a highway through the tolling area. Trajectories for each scenario were transformed in operating mode distributions for emissions estimates in MOVES, described further in the Emissions Modeling Document.

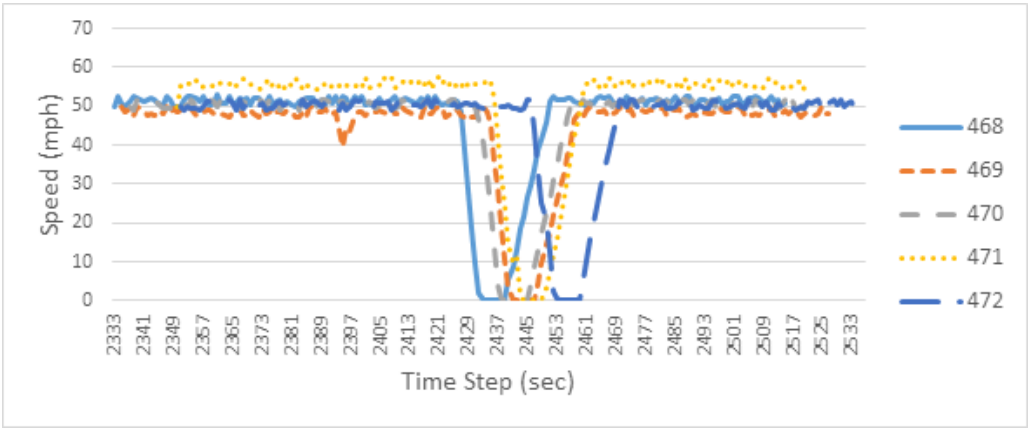


Figure 4. Representative second-by-second vehicle speed trajectories of the full stop tolling scenario in nonpeak traffic conditions, as modeled in SUMO traffic microsimulations

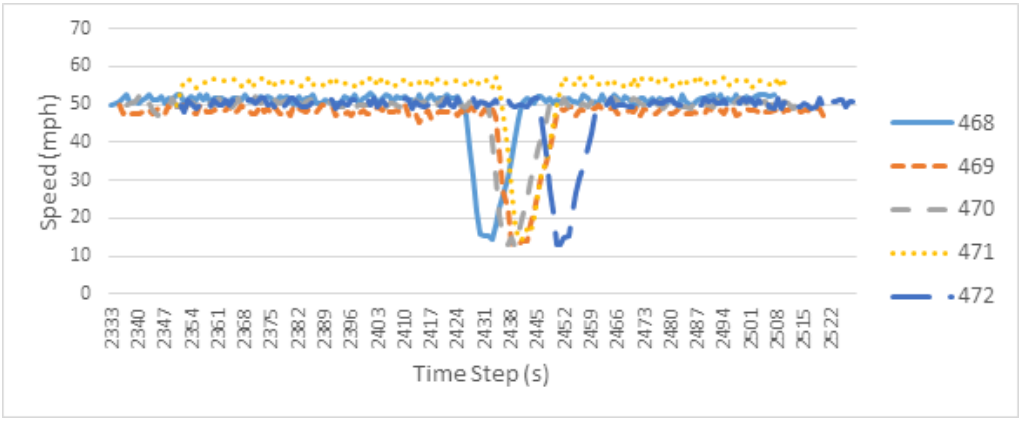


Figure 5. Representative second-by-second vehicle speed trajectories of the rolling cruise tolling scenario in nonpeak traffic conditions, as modeled in SUMO traffic microsimulations

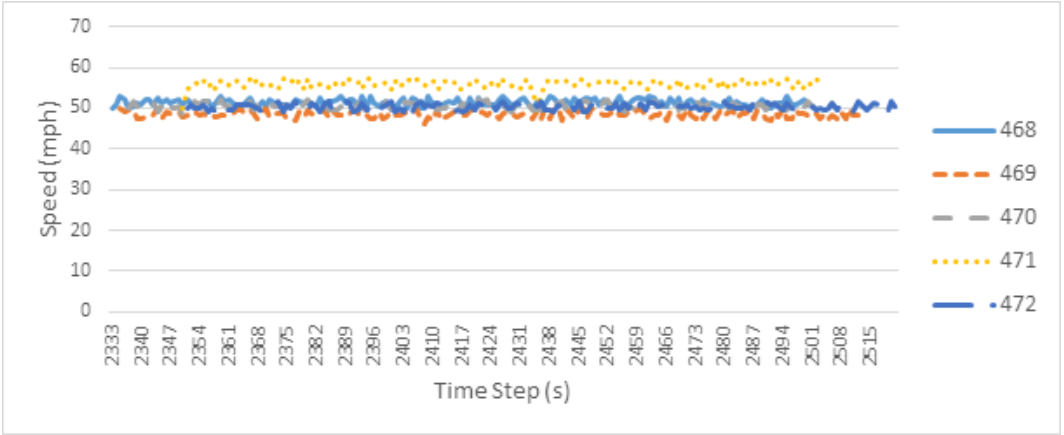


Figure 6. Representative second-by-second vehicle speed trajectories of the free flow tolling scenario in nonpeak traffic conditions, as modeled in SUMO traffic microsimulations