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 default-scale runs of the Motor Vehicle Emission Simulator (MOVES) as well as other data sources. For each tool in the Toolkit, the inputs, outputs and error messages 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, guidance on incorporating user-supplied emission rates, and the methodology used to calculate emissions benefits can be found in the accompanying documentation of the emissions data.

Adaptive Traffic Control Systems (ATCS) Tool

Traffic signal systems, which control traffic flows, are one of the most effective tools to reduce congestion. Most traffic signal systems are timed based on day-to-day, within-day, or within-peak-period variations of historical traffic patterns to optimize overall system performance. However, traffic signal systems fail to perform optimally when traffic patterns deviate from the time-of-day (TOD) variations upon which traffic signals were timed to operate. These fixed timing plans can cause excess delay, more stops, and longer queue lengths for vehicles which, in turn, increase fuel use and emissions.[1] Traffic signal timings in adaptive traffic control systems (ATCS) can adjust to changing traffic environments based on traffic volume data collected in by sensors deployed at individual intersections. As a category of intelligent transportation systems (ITS) and that sometimes employs vehicle to infrastructure communications technology, ATCS can more effectively regulate traffic by reducing excess delay, vehicle stops, and queue lengths compared to traffic signal systems based on TOD signal timing plans.[2] These performance improvements reduce pollutant emissions by reducing the overall amount of time it takes for vehicles to traverse a signalized corridor, in addition to reducing accelerations and decelerations and reducing idle time at stop lights. The ATCS CMAQ tool allows users to calculate corridor-wide daily emissions benefits from ATCS projects along a corridor that originally had a TOD signal timing plan.

This document is organized in 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 Examples section provides instructive examples of how to use the tool for project analysis. A description of the evolution of ATCS and examples of systems that have been deployed are provided in

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[1] Stevanovic, Aleksandar, Kergaye, Cameron, and Stevanovic, Jelka. (2012). Long-Term Benefits of Adaptive Traffic Control Under Varying Traffic Flows During Weekday Peak Hours. *Transportation Research Record: Journal of the Transportation Research Board*. doi: 10.3141/2311-09.

[2] Wang, Yizhe, Yang, Xiaoguang, Liang, Hailun, and Liu Yangdong. (2018). A Review of the Self-Adaptive Traffic Control System Based on Future Traffic Environment. *Journal of Advanced Transportation, 2018*. https://doi.org/10.1155/2018/1096123

the appendix. For more information about the methodology used to calculate the reduction in delay and how the default emissions data were developed for this tool, see the Tool Methodology section of this document.

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USER GUIDE

This section describes each user input and tool output, as well as the emissions reductions report, error messages, and other assumptions present in the Adaptive Traffic Control Systems (ATCS) Tool. The tool only contains one module which is designed for projects implementing ATCS on a corridor that originally had a time-of-day (TOD) signaling plan.

User Inputs

The ATCS 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 vehicles and road types involved in the ATCS project, specific to the measured or predicted traffic volumes and performance metrics relative in the user-input evaluation year. This tool is designed specifically to model benefits on individual corridor sections with ATCS deployed. If there are multiple sections of the ATCS or multiple major corridors included in these deployments, each section should be analyzed as separate corridors by running the tool multiple times. The user-defined inputs for the tool are described in Table 1.

Table 1. User Inputs

Question	User Input	Units	Description
(1)	Evaluation Year	-----	Use the drop-down menu to choose a year between 2018 and 2040.
(2)	Area Type	-----	Use the drop-down menu to indicate a rural or urban corridor. This setting determines the road type for the MOVES emissions rates (rural unrestricted or urban unrestricted).
(3)	Corridor Length	miles	Input the length of the project corridor along which the ATCS will be implemented. This distance is the driving distance along the main corridor roadway between the center of the first signalized intersection and the center of the last signalized intersection at which the adaptive system is being deployed.
(4)	Number of Signalized Intersections	-----	Input the number of traffic signals along the project corridor. This should indicate the number of consecutive signalized intersections included in the ATCS. If there is a gap in the corridor where ATCS is installed, these two corridor sections should be analyzed separately.
(5)	Total Peak Hours per Day (AM+PM)	hours	Input the total number of peak hours the corridor experiences on a typical weekday.

Question	User Input	Units	Description
(6)	Free Flow Speed or Posted Speed Limit	miles per hour	Input the speed limit that is posted for the project corridor, or the free flow speed for vehicles on the corridor. For more details on the difference between free flow speed and posted speed limit, see "Notes on Delay Reduction Methodology" below. In cases where speed limit varies within the project corridor or by direction, the average speed limit, weighted by relative distance of each different speed limit, should be used here. Or, this input can be back-calculated using free flow travel time metrics.
(7)	Total Volume on Corridor (Average of Both Directions)	vehicles/hour	Input the average weekday peak and non-peak hourly volumes of traffic as the average of both directions along the corridor.
(8)	Existing Total Corridor Delay (average of both directions)	seconds/vehicle	Input the average weekday existing delay as the average of both directions on the corridor during peak and non-peak hours. If field data is not available, you can approximate an appropriate delay value given the intersection's existing level of service (see Table 2 below) multiplied by the number of intersections in the project area. If travel-time data is available but existing delay data is not, existing total corridor delay can be calculated using travel time and the free-flow speed on the corridor.
(9)	Truck Percentage (average of both directions)	-----	Input the average percent of traffic that is heavy-duty truck vehicles during peak and non-peak hours. These percentages should be averages along the entire corridor and should represent both directions of the corridor.
(10)	Use Your Own Delay Reduction Values?	-----	This tool allows the user to input their own delay reduction values into the tool. These performance improvement metrics or estimates may be from field measurements of an already deployed ATCS system, or from microsimulations where an ATCS system is studied in a simulated environment.
(11)	Corridor Delay Reduction Per Vehicle (one direction)	seconds/vehicle	If the previous user input (10) is 'Yes', input the average weekday delay reduction per vehicle during peak and non-peak hours. Leave blank if the previous user input (10) is 'No'.

The tool interface also includes a reference table for Level of Service per intersection. This table is also included here in Table 2. The average level of service before the ATCS deployment is displayed on the interface as well. This output provides the user a representation of the average level of service of each intersection along the corridor. Level of Service (LOS) measurements are used to analyze traffic flow on different types of transportation facilities based on congestion and delay. For signalized, at-grade intersections, LOS is defined as a function of the average delay each vehicle can expect to experience at the intersection.

Table 2. Level of Service (LOS) Reference Table

LOS	Delay at each Signalized Intersection (s/veh)
A	0 - 10
B	>10 - 20
C	>20 - 35
D	>35 - 55
E	>55 - 80
F*	>80

*LOS F typically indicates that traffic demand has exceeded capacity (From HCM 2010, Exhibit 21-1).

Tool Outputs

Once the input parameters are entered, click the 'Calculate Output' button to generate results. Emission reduction 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. To return to default settings and clear input values, click the 'Reset to Default Values' button.

The tool reports (1) corridor performance and (2) emission reductions. The following corridor performance metrics are calculated for peak and non-peak hours, all of which are given as an average of both directions on the corridor:

- Corridor volume in vehicles per hour
- Existing corridor travel time in seconds
- Existing average speed in miles per hour
- Corridor delay reduction per vehicle in seconds
- New corridor delay per vehicle in seconds
- New average speed in miles per hour
- New average level of service per intersection

Note that the corridor volume values in the corridor performance section are the same as those in the inputs section.

Emission reductions are calculated in kilograms per year and then divided by 365 days to generate the CMAQ daily emission reductions reporting in kilograms per day for the following five criteria pollutants. Hourly emission reductions are also given for peak hours and non-peak hours.

- Carbon monoxide (CO)

- Particulate matter < 2.5 µm in diameter ($PM_{2.5}$)
- Particulate matter < 10 µm in diameter (PM_{10})
- Nitrogen oxides (NO_X)
- Volatile organic compounds (VOC)

Reductions in atmospheric carbon dioxide (CO_2) and carbon dioxide equivalents (CO_2e) in kilograms per day, and total energy consumption (TEC) in millions of British Thermal Units (MMBTU) are also provided. These parameters are calculated from greenhouse gas emissions reported by MOVES run outputs.

Note that a '0' value for an emission reduction indicates no change in emissions associated with the project. An 'NA' output value indicates that the output is not applicable based on the inputs provided. The emissions benefits are derived from the decrease in daily emissions resulting from a reduction of delay per vehicle as a result of ATCS deployment.

Emissions benefits are calculated by computing the average speed increase resulting from an overall reduction in delay. Generally, vehicles have lower emissions factors per distance travelled when travelling at higher speeds. Thus, the difference between emissions at speeds before the ATCS deployments and at speeds after deployment result in an emissions benefit (assuming average speed increases).

Error Messages

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

Table 3. Error Messages

Error Message	Reason for Error	Solution
Please make sure all inputs are supplied before attempting to calculate emissions benefits.	One or more inputs are missing.	Check that all inputs are supplied and provide any missing inputs.
Please make sure inputs are greater than 0.	One or more inputs are less than 0.	Check that all required inputs are greater than 0.
The number of peak hours per day is greater than 24. Please adjust the inputs and try again.	The number of peak hours exceeds 24.	Check that the number of peak hours input is less than or equal to 24.
The "Truck Percentage" inputs are greater than 100 percent. Please adjust the inputs and try again.	The truck percentage input exceeds a value of 100 percent.	Make sure truck percentage is less than or equal to 100%.

Error Message	Reason for Error	Solution
The current inputs cause an error in the delay reduction, please adjust the inputs and try again, or see the User Guide for further explanation.	One or more inputs are invalid for the delay reduction calculation.	Check that the delay per vehicle does not exceed the corridor travel time, the user input delay does not exceed the existing delay, and the user input delay reduction does not exceed corridor travel time. See the explanation below for further details.
One or more of the user-input delay reduction values is blank. Please input delay reduction values or uncheck the box in Question 10.	There are missing user input delay reduction inputs even though the user has chosen to provide their own delay reduction values.	Provide delay reduction values or uncheck the box in Question 10 to use the built-in model to estimate delay reduction values along the corridor.
The user-input delay reduction values are greater than the existing delay. Please adjust inputs and try again, or see the User Guide for further explanation.	User input delay reduction exceeds the existing delay along the corridor.	Make sure the user input delay reduction values do not exceed the existing delay along the corridor. See the explanation below for more details.

Warning Messages

Table 4 lists warning messages the user may encounter in this tool and the reason for the warning message, and a potential solution. In these cases, the user's inputs may have been intentional, and the tool will continue to calculate results if the user chooses to do so.

Table 4. Warning Messages

Warning Message	Reason for Warning	Potential Solution
The user-input delay reduction values are less than zero.	The user has chosen to use their own delay reduction values, but have input a value that is less than zero, indicating an increase in delay on the corridor.	Make sure the user-input delay values are correct. If the user intended to input an increase in delay, then click "OK" to continue with the emissions reduction calculations. If the user did not intend for the delay reduction values to be less than zero, then press "Cancel" to correct the error.

Warning Message	Reason for Warning	Potential Solution
The model does not predict any benefits from ATCS during one of the analysis periods.	The built-in method for estimating delay reduction from an ATCS deployment may result in a delay reduction value of 0 for some user input data. This means that for the relevant analysis period, the algorithm does not predict any delay reduction benefits from the deployment described by the current user inputs.	If the user inputs are intentional and accurate, then the results can be taken as-is. The adaptive system is most likely not able to reduce the existing delay in one of the analysis periods, or there are not enough vehicles to reduce the overall vehicle-delay on the corridor. Predicting disbenefits from ATCS deployments is outside of the bounds of the tool. Thus, there are no improvements predicted over the existing conditions. Since calculations are performed separately for peak and non-peak hour periods, this message may appear for one or both of the analysis periods. Larger delay reductions can be realized by increasing the existing delay inputs or the traffic flow volumes, but users should attempt to use inputs that represent the deployment they are analyzing as accurately as possible.

Notes on Delay Reduction Methodology

A detailed delay-reduction methodology description can be found in the methodology and emissions data documentation. Briefly, the increase in average speed and corresponding emissions benefits are based on Equation 1:

$$T = D + T_{free\ flow} \quad (1)$$

where

T = travel time along the corridor in seconds,

D = delay along the corridor (either before the ATCS has been deployed or after) in seconds, and

$T_{free\ flow}$ = travel time along the corridor at the free-flow speed in seconds.

This tool provides an input for posted speed limit or free flow speed along the corridor. Free flow speed is the maximum speed at which vehicles tend to travel on a roadway, unimpeded by congestion or traffic signals. While the posted speed limit is the ideal safest speed along a corridor at which vehicles travel, this often differs from the actual speed drivers tend to use on a specific roadway when unimpeded. Many methodologies exist for estimating free flow speed on a corridor. Usually these are adjustments of the posted speed limit and include factors for the number of lanes on the roadway, the width of each lane, existence of parking spots, and others. If the user has information on the free flow speed on the roadway, they should use that as the input in question number 6. If this information is not available, the posted speed limit is a reasonable proxy for free flow speed and users can use this as the input for question number 6.

The free flow travel time is calculated using the user input posted speed limit or free flow speed. Thus, the actual travel time is calculated as the free flow travel time plus the average delay per vehicle along the corridor. In the "before" scenario, *D* represents the existing average delay along the entire corridor per vehicle. Thus, the overall delay reduction as a result of ATCS deployment cannot be greater than the existing delay along the corridor. If all or close to all of the delay is reduced in the "after" scenario, vehicles are traveling close to the posted speed limit on the corridor. If the delay reduction is greater than the existing delay, then actual travel in the "after" scenario will be less than the free flow travel time and vehicles would be traveling faster than the posted speed limit. The tool makes sure that the predicted delay reduction values are not greater than the existing delay in the "before" scenario so this issue is avoided. However, if the user chooses to provide their own delay reduction values, an error is issued if these user input values are greater than the existing delay on the corridor.

In addition, Equation 1 is a useful and simple way to estimate existing delay along a corridor. The user simply subtracts the estimated free-flow travel time (or speed limit) along the corridor, $T_{free\ flow}$, from the existing average travel time, *T*, to estimate the average existing delay per vehicle, *D*. This method ensures that predicted average speeds as a result of ATCS deployment are not greater than the free-flow speed along the corridor, and avoids the issues outlined in the previous paragraph.

TOOL METHODOLOGY

The methodology underlying the development of the tool is based on a meta-analysis of delay reduction data collected from before-and-after studies of corridors where an adaptive signal timing system was deployed in place of a TOD signaling plan. Data and studies included in the meta-analysis are considered to be representative of the current state of the practice in adaptive signal timing and synchronization, and therefore the results can be used to estimate emissions benefits from a variety of adaptive systems. A more comprehensive explanation of the methodology used to estimate emissions benefits and the meta-analysis performed to develop this methodology is described in the methodology and emissions data documentation.

Emissions Data Sources

See the methodology and emissions data documentation for details about the activity and emissions equations used. Emission rates for the tool were derived from EPA's MOVES model. MOVES3 project-

level runs were used to determine running and idling emission rates at different speeds across varying road types for this tool.[3]

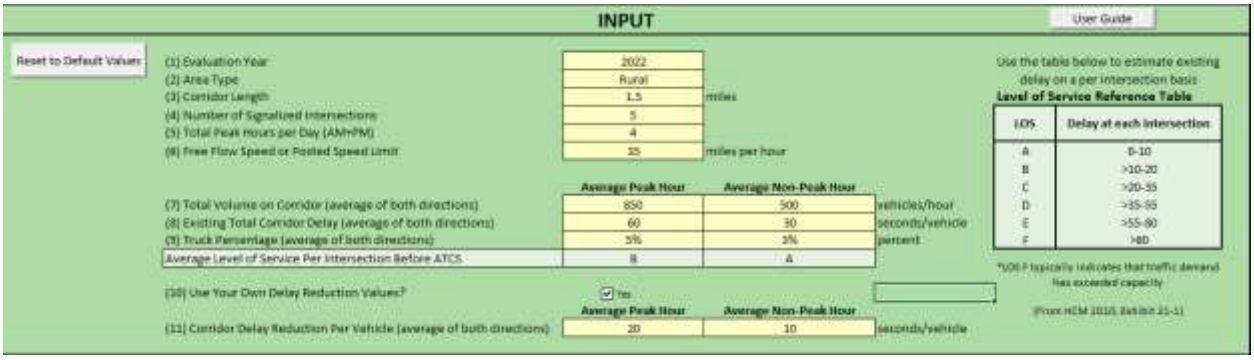
EXAMPLES

The examples below describe scenarios in which the ATCS Tool may be used.

Example 1: Known Delay Reduction Values

A rural municipality is considering upgrading 5 TOD-signalized intersections using ATCS along a main street in their downtown area. The municipality has run simulations of the corridor using a traffic microsimulation model and a virtual implementation of the adaptive system. These studies resulted in an anticipated delay reduction of 20 s/vehicle and 10 s/vehicle during peak and non-peak hours, respectively, for the 1.5-mi corridor.

In the tool, the user would select the following inputs, as shown in the image below.

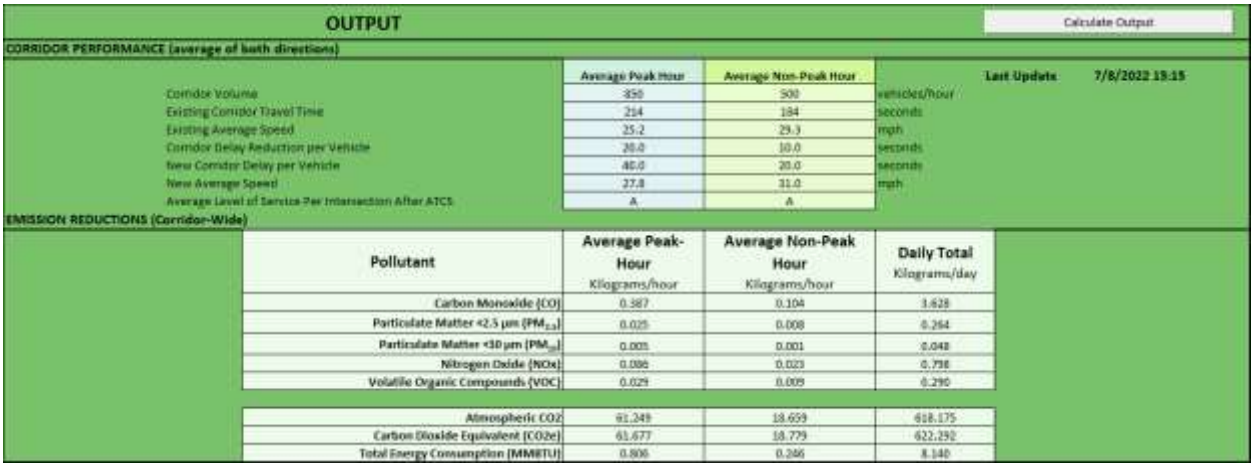


(1) Evaluation year: 2022
(2) Area type: Rural
(3) Corridor length: 1.5 miles
(4) Number of signalized intersections: 5
(5) Total peak hours per day: 4 hours
(6) Free flow speed or posted speed limit: 35 mph
(7) Total volume on corridor: 850 vehicles/hour (peak), 500 vehicles/hour (non-peak)
(8) Existing total corridor delay: 60 seconds/vehicle (peak), 30 seconds/vehicle (non-peak)
(9) Truck percentage: 5% (peak), 3% (non-peak)
(10) Use your own delay reduction values? Yes
(11) Corridor delay reduction per vehicle: 20 seconds/vehicle (peak), 10 seconds/vehicle (non-peak)

As automatically calculated, LOS is currently level B during peak hours and level A during non-peak hours.

Click the 'Calculate Output' button to generate results.

[3] https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves



OUTPUT — Calculate Output

CORRIDOR PERFORMANCE (average of both directions)

Last Update: 7/8/2022 19:15

	Average Peak Hour	Average Non-Peak Hour	
Corridor Volume	850	500	vehicles/hour
Existing Corridor Travel Time	214	184	seconds
Existing Average Speed	25.2	29.3	mph
Corridor Delay Reduction per Vehicle	20.0	10.0	seconds
New Corridor Delay per Vehicle	40.0	20.0	seconds
New Average Speed	27.8	31.0	mph
Average Level of Service Per Intersection After ATCS	A	A	

EMISSION REDUCTIONS (Corridor-Wide)

Pollutant	Average Peak-Hour Kilograms/hour	Average Non-Peak Hour Kilograms/hour	Daily Total Kilograms/day
Carbon Monoxide (CO)	0.387	0.104	3.628
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.025	0.008	0.264
Particulate Matter <10 µm (PM_{10})	0.005	0.001	0.048
Nitrogen Oxide (NOx)	0.086	0.023	0.798
Volatile Organic Compounds (VOC)	0.029	0.009	0.290
Atmospheric CO2	61.249	18.659	618.175
Carbon Dioxide Equivalent (CO2e)	61.677	18.779	622.292
Total Energy Consumption (MMBTU)	0.806	0.266	8.140

The calculated corridor performance measures are as follows:

Corridor Volume: 850 veh/hr (peak), 500 veh/hr (non-peak)
Existing Corridor Travel Time: 214 seconds (peak), 184 seconds (non-peak)
Existing Average Speed: 25.2 mph (peak), 29.3 mph (non-peak)
Corridor Delay Reduction per Vehicle: 20.0 seconds (peak), 10.0 seconds (non-peak)
New Corridor Delay per Vehicle: 40.0 seconds (peak), 20.0 seconds (non-peak)
New Average Speed: 27.8 mph (peak), 31.0 mph (non-peak)
Average Level of Service Per Intersection After ATCS: A (peak), A (non-peak)

The total daily emissions reductions and energy consumption are as follows:

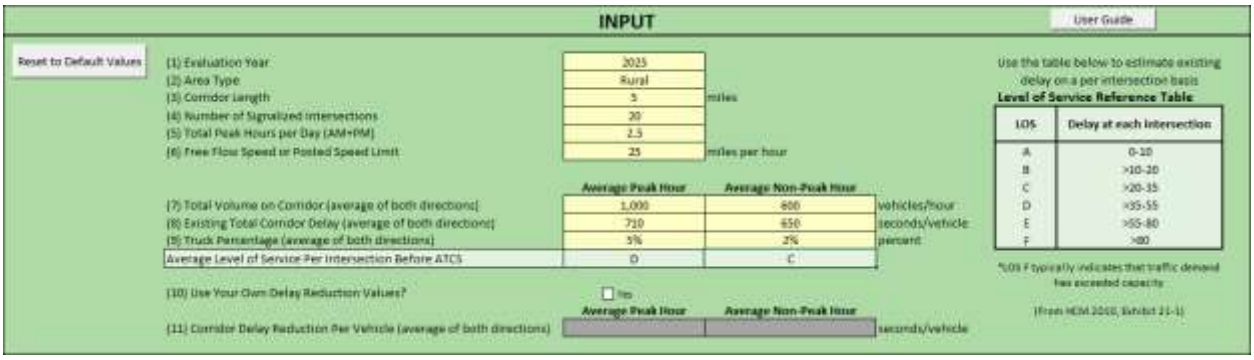
Carbon Monoxide (CO): 3.628 kg/d
Particulate Matter <2.5 µm (PM2.5): 0.264 kg/d
Particulate Matter <10 µm (PM10): 0.048 kg/d
Nitrogen Oxide (NOx): 0.798 kg/d
Volatile Organic Compounds (VOC): 0.290 kg/d

Atmospheric CO_2: 618.175 kg/d
Carbon Dioxide Equivalent (CO2e): 622.292 kg/d
Total Energy Consumption (TEC): 8.140 MMBTU

Example 2: Unknown Delay Reduction Values

A town receives many complaints about traffic delays and congestion along a 5-mi corridor with 20 signalized intersections. Crash data also suggest a higher crash frequency along this corridor compared to similar corridors in the surrounding area. Instead of retiming the TOD signals, the town is considering ATCS. They have not completed simulation studies or estimated delay reduction resulting from the deployment.

In the tool, the user would select the following inputs, as shown in the image below.



INPUT

User Guide

Reset to Default Values

(1) Evaluation Year	2025		
(2) Area Type	Rural		
(3) Corridor Length	5	miles	
(4) Number of Signalized Intersections	20		
(5) Total Peak Hours per Day (AM+PM)	2.5		
(6) Free Flow Speed or Posted Speed Limit	25	miles per hour	

	Average Peak Hour	Average Non-Peak Hour	
(7) Total Volume on Corridor (average of both directions)	1,000	600	vehicles/hour
(8) Existing Total Corridor Delay (average of both directions)	710	650	seconds/vehicle
(9) Truck Percentage (average of both directions)	5%	2%	percent
Average Level of Service Per Intersection Before ATCS	D	C	

(10) Use Your Own Delay Reduction Values? ☐ Yes

	Average Peak Hour	Average Non-Peak Hour	
(11) Corridor Delay Reduction Per Vehicle (average of both directions)			seconds/vehicle

Use the table below to estimate existing delay on a per intersection basis

Level of Service Reference Table

LOS	Delay at each Intersection
A	0-10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

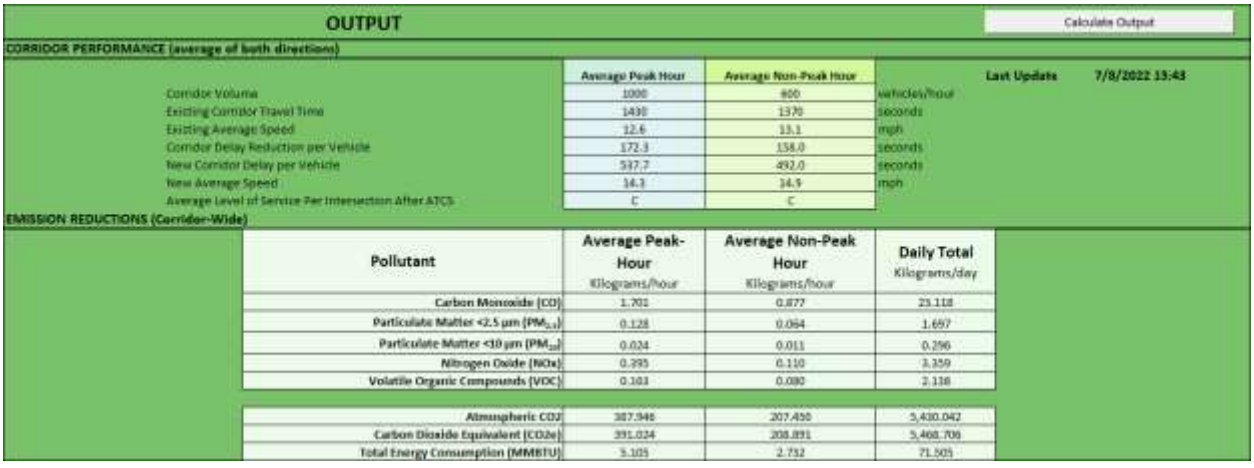
*LOS F typically indicates that traffic demand has exceeded capacity

(From HCM 2010, Exhibit 21-1)

(1) Evaluation year: 2025
(2) Area type: Rural
(3) Corridor length: 5 miles
(4) Number of signalized intersections: 20
(5) Total peak hours per day: 2.5 hours
(6) Free flow speed or posted speed limit: 25 mph
(7) Total volume on corridor: 1000 vehicles/hour (peak), 600 vehicles/hour (non-peak)
(8) Existing total corridor delay: 710 seconds/vehicle (peak), 650 seconds/vehicle (non-peak)
(9) Truck percentage: 5% (peak), 2% (non-peak)
(10) Use your own delay reduction values? No
(11) Corridor delay reduction per vehicle: N/A

As automatically calculated, LOS is currently level D during peak hours and level C during non-peak hours.

Click the 'Calculate Output' button to generate results.



OUTPUT

Calculate Output

CORRIDOR PERFORMANCE (average of both directions)

Last Update 7/8/2022 13:43

	Average Peak Hour	Average Non-Peak Hour	
Corridor Volume	1000	600	vehicles/hour
Existing Corridor Travel Time	1430	1370	seconds
Existing Average Speed	12.6	13.1	mph
Corridor Delay Reduction per Vehicle	172.3	158.0	seconds
New Corridor Delay per Vehicle	537.7	492.0	seconds
New Average Speed	14.3	14.9	mph
Average Level of Service Per Intersection After ATCS	C	C	

EMISSION REDUCTIONS (Corridor-Wide)

Pollutant	Average Peak-Hour Kilograms/hour	Average Non-Peak Hour Kilograms/hour	Daily Total Kilograms/day
Carbon Monoxide (CO)	1.701	0.877	23.118
Particulate Matter <2.5 μm ($PM_{2.5}$)	0.128	0.064	1.697
Particulate Matter <10 μm (PM_{10})	0.024	0.011	0.296
Nitrogen Oxide (NOx)	0.395	0.110	3.359
Volatile Organic Compounds (VOC)	0.163	0.080	2.138
Atmospheric CO2	387.946	207.450	5,430.042
Carbon Dioxide Equivalent (CO_{2e})	391.024	208.891	5,468.709
Total Energy Consumption (MMBTU)	5.105	2.732	71.505

The calculated performance measures are as follows:

Corridor Volume: 1000 veh/hr (peak), 600 veh/hr (non-peak)
Existing Corridor Travel Time: 1430 seconds (peak), 1370 seconds (non-peak)
Existing Average Speed: 12.6 mph (peak), 13.1 mph (non-peak)
Corridor Delay Reduction per Vehicle: 172.3 seconds (peak), 158.0 seconds (non-peak)

New Corridor Delay per Vehicle: 537.7 seconds (peak), 492.0 seconds (non-peak)
New Average Speed: 14.3 mph (peak), 14.9 mph (non-peak)
Average Level of Service Per Intersection After ATCS: C (peak), C (non-peak)

The total daily emissions reductions and energy consumption are as follows:

Carbon Monoxide (CO): 23.118 kg/d
Particulate Matter <2.5 µm (PM2.5): 1.697 kg/d
Particulate Matter <10 µm (PM10): 0.296 kg/d
Nitrogen Oxide (NOx): 3.359 kg/d
Volatile Organic Compounds (VOC): 2.138 kg/ds

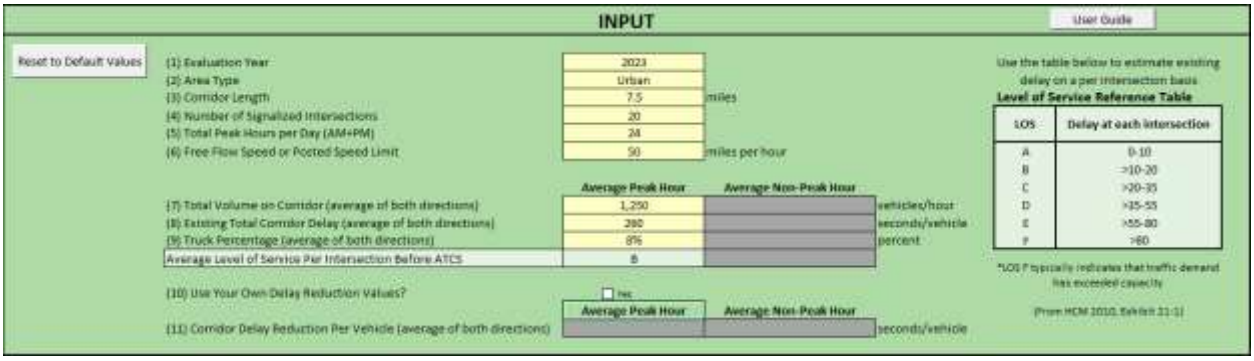
Atmospheric CO_2: 5,430.042 kg/d
Carbon Dioxide Equivalents (CO2e): 5,468.706 kg/d
Total Energy Consumption (TEC): 71.505 MMBTU

Example 3: Separate Analysis Periods

A 7.5-mi corridor has numerous shopping complexes and is undergoing housing redevelopment. Twenty TOD signals currently regulate traffic flows. The local department of transportation is considering ATCS to accommodate seasonal traffic flows and future increased peak flows. The delay reduction per vehicle is not yet known. Additionally, the city is interested in the hourly emissions benefits during the morning and evening peak periods of the day, as well as during average weekend hours when traffic to the shopping complexes often increases dramatically.

To analyze this scenario, the user needs to run the tool separately for each analysis period. Benefits on a per hour basis can be obtained by using "24" as the input for the number of peak hours per day. Hourly benefits can be taken from the "Average Peak-Hour" column in the output table of the tool.

To analyze the morning peak, the user would select the following inputs in the tool, as shown in the image below.

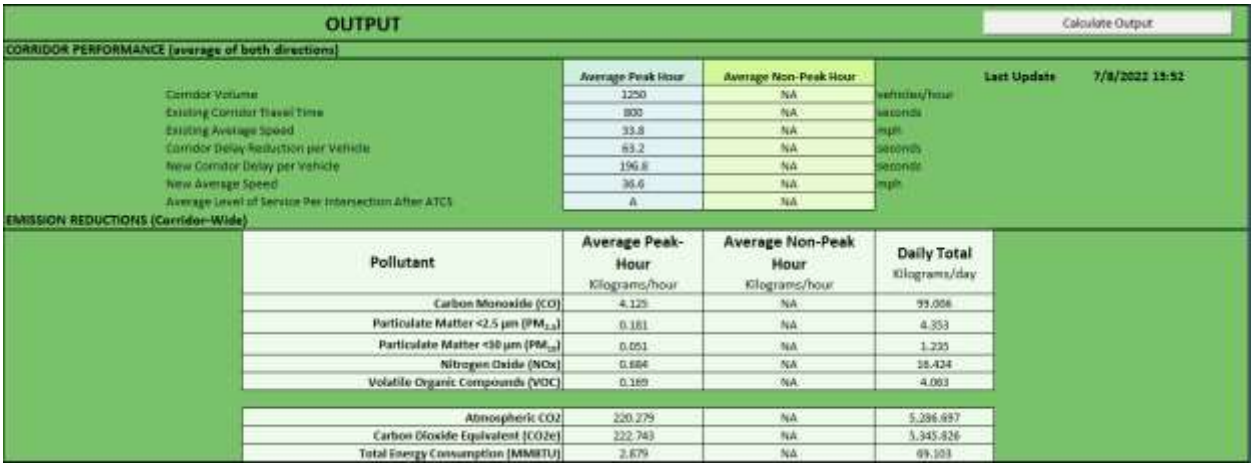


(1) Evaluation year: 2023
(2) Area type: Urban
(3) Corridor length: 7.5 miles
(4) Number of signalized intersections: 20

(5) Total peak hours per day: 24 hours
(6) Free flow speed or posted speed limit: 50 mph
(7) Total volume on corridor: 1250 vehicles/hour (peak), N/A (non-peak)
(8) Existing total corridor delay: 260 seconds/vehicle (peak), N/A (non-peak)
(9) Truck percentage: 8% (peak), N/A (non-peak)
(10) Use your own delay reduction values? No
(11) Corridor delay reduction per vehicle: N/A

As automatically calculated, LOS is currently level B during morning peak hours.

Click the 'Calculate Output' button to generate results.



OUTPUT — Calculate Output

CORRIDOR PERFORMANCE (average of both directions)

Last Update 7/8/2022 13:52

	Average Peak Hour	Average Non-Peak Hour	
Corridor Volume	1250	NA	vehicles/hour
Existing Corridor Travel Time	800	NA	seconds
Existing Average Speed	33.8	NA	mph
Corridor Delay Reduction per Vehicle	63.2	NA	seconds
New Corridor Delay per Vehicle	196.8	NA	seconds
New Average Speed	36.6	NA	mph
Average Level of Service Per Intersection After ATCS	A	NA	

EMISSION REDUCTIONS (Corridor-Wide)

Pollutant	Average Peak-Hour Kilograms/hour	Average Non-Peak Hour Kilograms/hour	Daily Total Kilograms/day
Carbon Monoxide (CO)	4.125	NA	99.006
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.181	NA	4.353
Particulate Matter <10 µm (PM_{10})	0.051	NA	1.235
Nitrogen Oxide (NOx)	0.684	NA	16.424
Volatile Organic Compounds (VOC)	0.169	NA	4.063

Atmospheric CO2	220.279	NA	5,286.697
Carbon Dioxide Equivalent (CO2e)	222.743	NA	5,345.826
Total Energy Consumption (MMBTU)	2.879	NA	69.103

In this case, only the peak hour outputs are relevant. The calculated corridor performance measures are as follows:

Corridor Volume: 1250 veh/hr (peak), NA (non-peak)
Existing Corridor Travel Time: 800 seconds (peak), NA (non-peak)
Existing Average Speed: 33.8 mph (peak), NA (non-peak)
Corridor Delay Reduction per Vehicle: 63.2 seconds (peak), NA (non-peak)
New Corridor Delay per Vehicle: 196.8 seconds (peak), NA (non-peak)
New Average Speed: 36.6 mph (peak), NA (non-peak)
Average Level of Service Per Intersection After ATCS: A (peak), NA (non-peak)

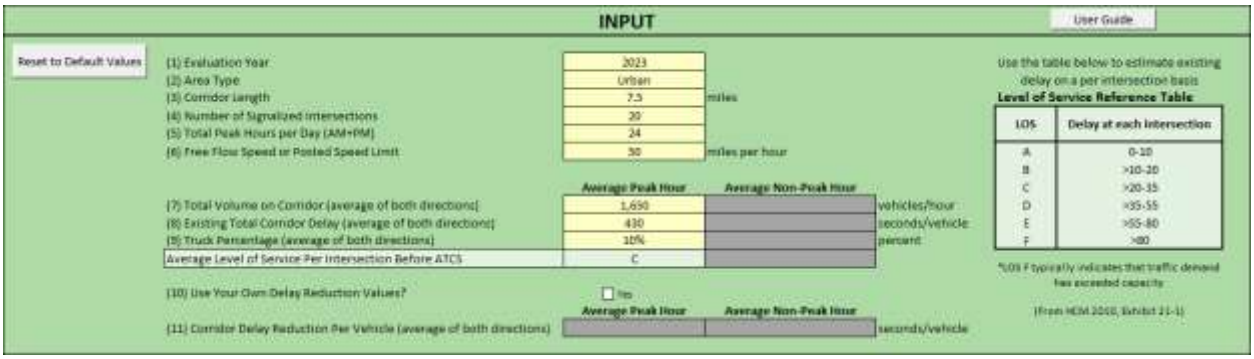
The hourly emissions reductions and energy consumption for the morning average peak hour period are as follows:

Carbon Monoxide (CO): 4.125 kg/hr
Particulate Matter <2.5 µm (PM2.5): 0.181 kg/hr
Particulate Matter <10 µm (PM10): 0.051 kg/hr
Nitrogen Oxide (NOx): 0.684 kg/hr
Volatile Organic Compounds (VOC): 0.169 kg/hr

Atmospheric CO_2: 220.279 kg/hr

Carbon Dioxide Equivalents (CO2e): 222.743 kg/hr
Total Energy Consumption (TEC): 2.879 MMBTU

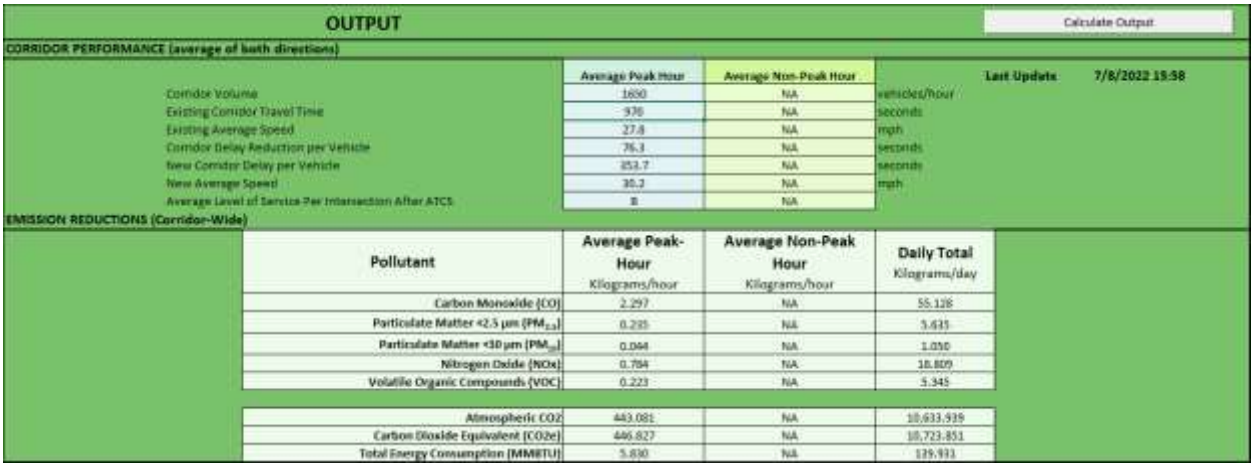
To analyze the evening peak, the user would select the following inputs in the tool, as shown in the image below.



(1) Evaluation year: 2023
(2) Area type: Urban
(3) Corridor length: 7.5 miles
(4) Number of signalized intersections: 20
(5) Total peak hours per day: 24 hours
(6) Free flow speed or posted speed limit: 50 mph
(7) Total volume on corridor: 1650 vehicles/hour (peak), N/A (non-peak)
(8) Existing total corridor delay: 430 seconds/vehicle (peak), N/A (non-peak)
(9) Truck percentage: 10% (peak), N/A (non-peak)
(10) Use your own delay reduction values? No
(11) Corridor delay reduction per vehicle: N/A

As automatically calculated, LOS is currently level C during evening peak hours.

Click the 'Calculate Output' button to generate results.



In this case, only the peak hour outputs are relevant. The calculated corridor performance measures are as follows:

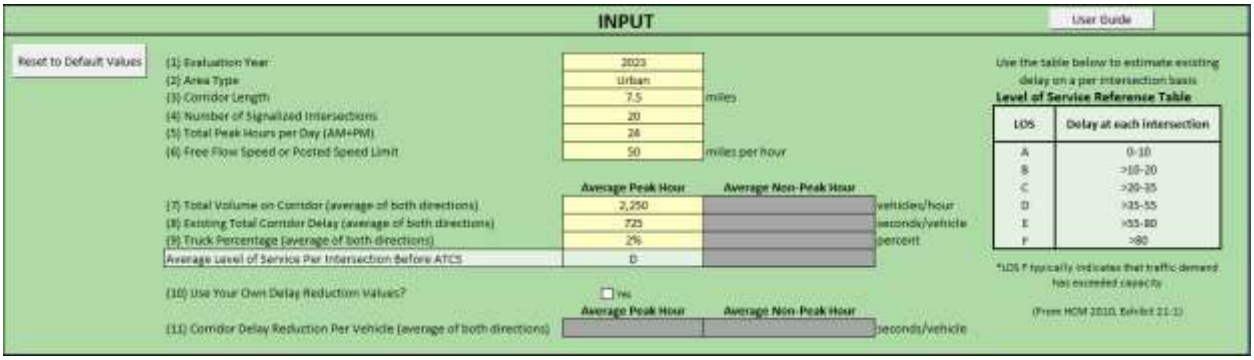
Corridor Volume: 1650 veh/hr (peak), NA (non-peak)
Existing Corridor Travel Time: 970 seconds (peak), NA (non-peak)
Existing Average Speed: 27.8 mph (peak), NA (non-peak)
Corridor Delay Reduction per Vehicle: 76.3 seconds (peak), NA (non-peak)
New Corridor Delay per Vehicle: 353.7 seconds (peak), NA (non-peak)
New Average Speed: 30.2 mph (peak), NA (non-peak)
Average Level of Service Per Intersection After ATCS: B (peak), NA (non-peak)

The hourly emissions reductions and energy consumption for the evening peak are as follows:

Carbon Monoxide (CO): 2.297 kg/hr
Particulate Matter <2.5 µm (PM2.5): 0.235 kg/hr
Particulate Matter <10 µm (PM10): 0.044 kg/hr
Nitrogen Oxide (NOx): 0.784 kg/hr
Volatile Organic Compounds (VOC): 0.223 kg/hr

Atmospheric CO_2: 443.081 kg/hr
Carbon Dioxide Equivalents (CO2e): 446.827 kg/hr
Total Energy Consumption (TEC): 5.830 MMBTU

To analyze benefits during an average weekend hour, the user would select the following inputs in the tool, as shown in the image below.



(1) Evaluation year: 2023
(2) Area type: Urban
(3) Corridor length: 7.5 miles
(4) Number of signalized intersections: 20
(5) Total peak hours per day: 24 hours
(6) Free flow speed or posted speed limit: 50 mph
(7) Total volume on corridor: 2250 vehicles/hour (peak), N/A (non-peak)
(8) Existing total corridor delay: 725 seconds/vehicle (peak), N/A (non-peak)
(9) Truck percentage: 2% (peak), N/A (non-peak)
(10) Use your own delay reduction values? No
(11) Corridor delay reduction per vehicle: N/A

As automatically calculated, LOS is currently level D during weekend hours.

Click the 'Calculate Output' button to generate results.

OUTPUT — Calculate Output

CORRIDOR PERFORMANCE (average of both directions)

Last Update: 7/8/2022 16:08

	Average Peak Hour	Average Non-Peak Hour	
Corridor Volume	2250	NA	vehicles/hour
Existing Corridor Travel Time	1265	NA	seconds
Existing Average Speed	21.3	NA	mph
Corridor Delay Reduction per Vehicle	92.5	NA	seconds
New Corridor Delay per Vehicle	632.5	NA	seconds
New Average Speed	23.0	NA	mph
Average Level of Service Per Intersection After ATCS	C	NA	

EMISSION REDUCTIONS (Corridor-Wide)

Pollutant	Average Peak-Hour Kilograms/hour	Average Non-Peak Hour Kilograms/hour	Daily Total Kilograms/day
Carbon Monoxide (CO)	7.457	NA	178.962
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.090	NA	2.159
Particulate Matter <10 µm (PM_{10})	0.027	NA	0.647
Nitrogen Oxide (NOx)	0.419	NA	10.060
Volatile Organic Compounds (VOC)	0.247	NA	5.939
Atmospheric CO_2	558.928	NA	13,414.288
Carbon Dioxide Equivalent (CO_2e)	562.957	NA	13,510.960
Total Energy Consumption (MMBTU)	7.358	NA	176.588

In this case, only the peak hour outputs are relevant. The calculated corridor performance measures are as follows:

Corridor Volume: 2250 veh/hr (peak), NA (non-peak)
Existing Corridor Travel Time: 1265 seconds (peak), NA (non-peak)
Existing Average Speed: 21.3 mph (peak), NA (non-peak)
Corridor Delay Reduction per Vehicle: 92.5 seconds (peak), NA (non-peak)
New Corridor Delay per Vehicle: 632.5 seconds (peak), NA (non-peak)
New Average Speed: 23.0 mph (peak), NA (non-peak)
Average Level of Service Per Intersection After ATCS: C (peak), NA (non-peak)

The hourly emissions reductions and energy consumption during weekend hours are as follows:

Carbon Monoxide (CO): 7.457 kg/hr
Particulate Matter <2.5 µm (PM2.5): 0.090 kg/hr
Particulate Matter <10 µm (PM10): 0.027 kg/hr
Nitrogen Oxide (NOx): 0.419 kg/hr
Volatile Organic Compounds (VOC): 0.247 kg/hr

Atmospheric CO_2: 558.928 kg/hr
Carbon Dioxide Equivalents (CO2e): 562.957 kg/hr
Total Energy Consumption (TEC): 7.358 MMBTU

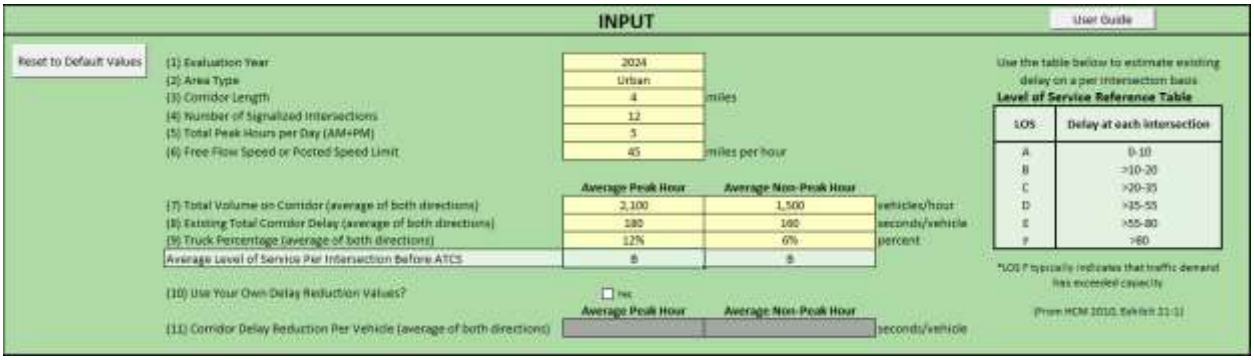
Example 4: Special Event Analysis

A main corridor with 12 TOD-signalized intersections grants access to a large venue that hosts concerts, sports games, and other special events. The surrounding agencies are considering ATCS to better accommodate the unpredictable traffic flows along this 4-mi corridor. The delay reduction per vehicle is

not yet known. Additionally, the agencies would like to understand how the hourly emissions benefits during special events differ from typical daily emissions benefits.

The user needs to analyze daily emissions benefits separately from special events.

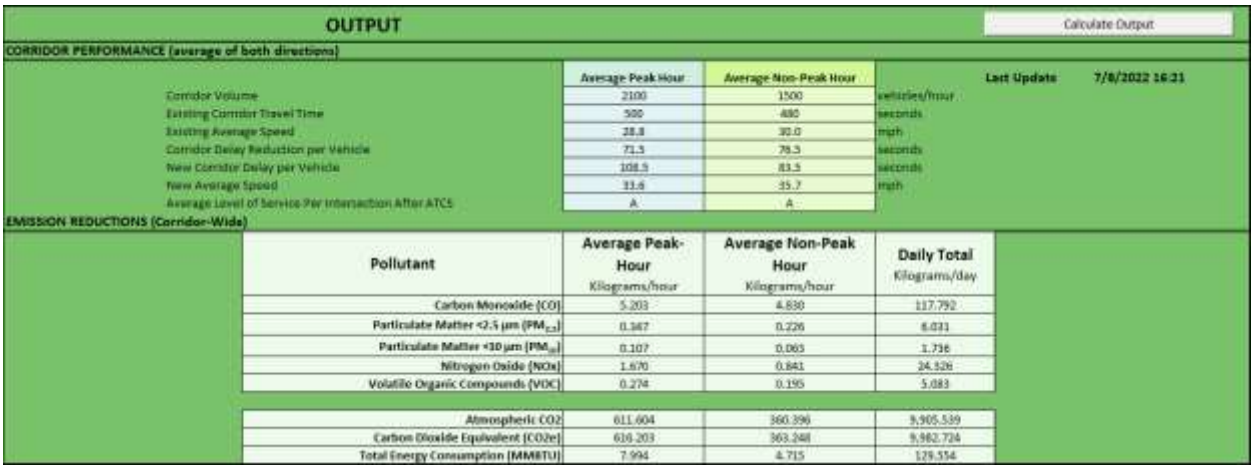
To analyze daily emissions benefits, the user would select the following inputs in the tool, as shown in the image below.



(1) Evaluation year: 2024
(2) Area type: Urban
(3) Corridor length: 4 miles
(4) Number of signalized intersections: 12
(5) Total peak hours per day: 5 hours
(6) Free flow speed or posted speed limit: 45 mph
(7) Total volume on corridor: 2100 vehicles/hour (peak), 1500 vehicles/hour (non-peak)
(8) Existing total corridor delay: 180 seconds/vehicle (peak), 160 seconds/vehicle (non-peak)
(9) Truck percentage: 12% (peak), 6% (non-peak)
(10) Use your own delay reduction values? No
(11) Corridor delay reduction per vehicle: N/A

As automatically calculated, LOS is currently level B during both peak and non-peak hours.

Click the 'Calculate Output' button to generate results.



The calculated corridor performance measures are as follows:

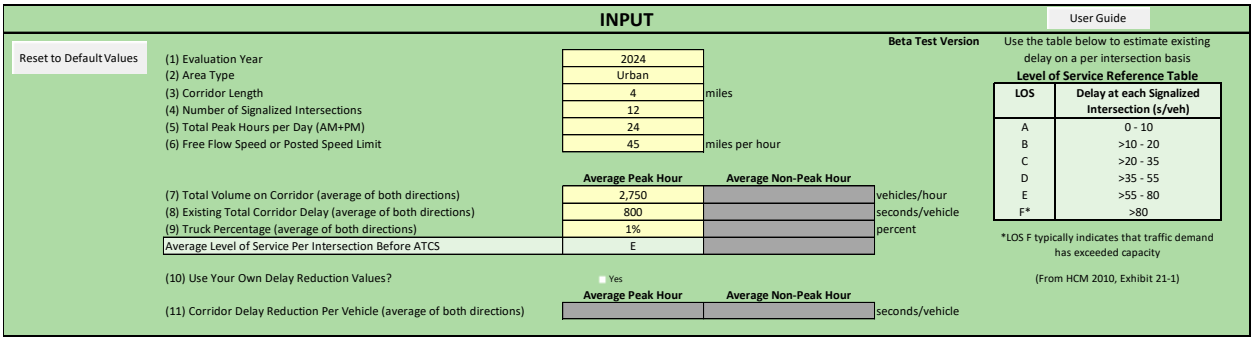
Corridor Volume: 2100 veh/hr (peak), 1500 veh/hr (non-peak)
Existing Corridor Travel Time: 500 seconds (peak), 480 seconds (non-peak)
Existing Average Speed: 28.8 mph (peak), 30.0 mph (non-peak)
Corridor Delay Reduction per Vehicle: 71.5 seconds (peak), 76.5 seconds (non-peak)
New Corridor Delay per Vehicle: 180.5 seconds (peak), 83.5 seconds (non-peak)
New Average Speed: 33.6 mph (peak), 35.7 mph (non-peak)
Average Level of Service Per Intersection After ATCS: A (peak), A (non-peak)

The total daily emissions reductions and energy consumption are as follows:

Carbon Monoxide (CO): 117.792 kg/d
Particulate Matter <2.5 µm (PM2.5): 6.031 kg/d
Particulate Matter <10 µm (PM10): 1.736 kg/d
Nitrogen Oxide (NOx): 24.326 kg/d
Volatile Organic Compounds (VOC): 5.083 kg/d

Atmospheric CO_2: 9,905.539 kg/d
Carbon Dioxide Equivalents (CO2e): 9,989.724 kg/d
Total Energy Consumption (TEC): 129.554 MMBTU

To analyze hourly emissions benefits during special events, the user would select the following inputs in the tool, as shown in the image below.

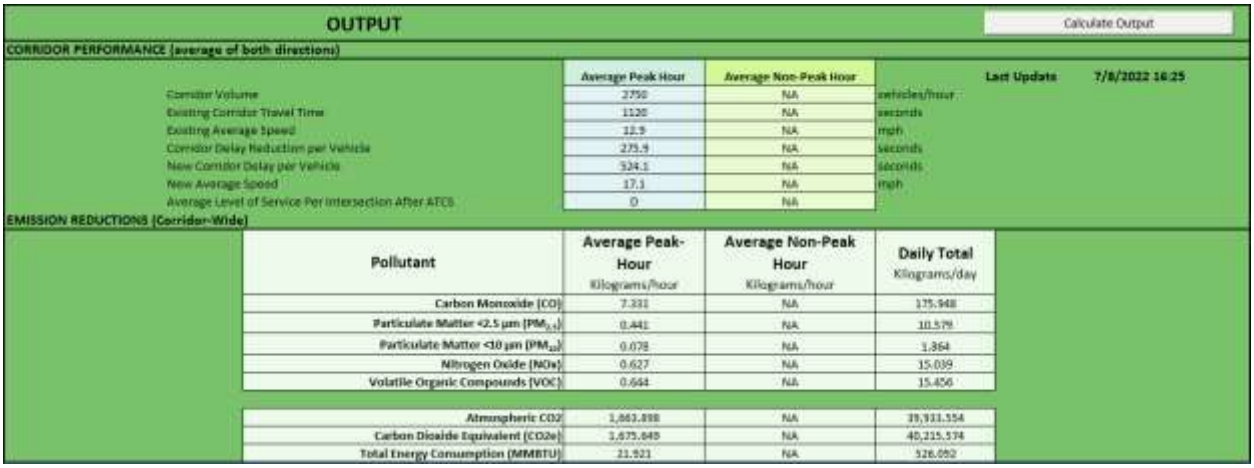


(1) Evaluation year: 2024
(2) Area type: Urban
(3) Corridor length: 4 miles
(4) Number of signalized intersections: 12
(5) Total peak hours per day: 24 hours
(6) Free flow speed or posted speed limit: 45 mph
(7) Total volume on corridor: 2750 vehicles/hour (peak), N/A (non-peak)
(8) Existing total corridor delay: 800 seconds/vehicle (peak), N/A (non-peak)
(9) Truck percentage: 1% (peak), N/A (non-peak)
(10) Use your own delay reduction values? No

(11) Corridor delay reduction per vehicle: N/A

As automatically calculated, LOS is currently level E during special events.

Click the 'Calculate Output' button to generate results.



OUTPUT

Calculate Output

CORRIDOR PERFORMANCE (average of both directions)

Last Update 7/8/2022 16:25

	Average Peak Hour	Average Non-Peak Hour	
Corridor Volume	2750	NA	vehicles/hour
Existing Corridor Travel Time	1120	NA	seconds
Existing Average Speed	12.9	NA	mph
Corridor Delay Reduction per Vehicle	275.9	NA	seconds
New Corridor Delay per Vehicle	524.1	NA	seconds
New Average Speed	17.1	NA	mph
Average Level of Service Per Intersection After ATCS	D	NA	

EMISSION REDUCTIONS (Corridor-Wide)

Pollutant	Average Peak-Hour Kilograms/hour	Average Non-Peak Hour Kilograms/hour	Daily Total Kilograms/day
Carbon Monoxide (CO)	7.331	NA	175.948
Particulate Matter <2.5 µm ($PM_{2.5}$)	0.441	NA	10.579
Particulate Matter <10 µm (PM_{10})	0.078	NA	1.864
Nitrogen Oxide (NOx)	0.627	NA	15.039
Volatile Organic Compounds (VOC)	0.644	NA	15.456
Atmospheric CO2	1,663.898	NA	39,933.554
Carbon Dioxide Equivalent (CO2e)	1,675.649	NA	40,215.574
Total Energy Consumption (MMBTU)	21.921	NA	526.092

In this case, only the peak hour outputs are relevant. The calculated corridor performance measures are as follows:

Corridor Volume: 2750 veh/hr (peak), NA (non-peak)
Existing Corridor Travel Time: 1120 second (peak), NA (non-peak)
Existing Average Speed: 12.9 mph (peak), NA (non-peak)
Corridor Delay Reduction per Vehicle: 275.9 seconds (peak), NA (non-peak)
New Corridor Delay per Vehicle: 524.1 seconds (peak), NA (non-peak)
New Average Speed: 17.1 mph (peak), NA (non-peak)
Average Level of Service Per Intersection After ATCS: D (peak), NA (non-peak)

The hourly emissions reductions and energy consumption during special events are as follows:

Carbon Monoxide (CO): 7.331 kg/hr
Particulate Matter <2.5 µm (PM2.5): 0.441 kg/hr
Particulate Matter <10 µm (PM10): 0.078 kg/hr
Nitrogen Oxide (NOx) 0.627 kg/hr
Volatile Organic Compounds (VOC): 0.644 kg/hr

Atmospheric CO_2: 1,663.898 kg/hr
Carbon Dioxide Equivalents (CO2e): 1,675.649 kg/hr
Total Energy Consumption (TEC): 21.921 MMBTU

Appendix – Evolution of Adaptive Traffic Control Systems

During the past 30 years, over 20 ATCS implementations have been developed but only about half of these systems have been deployed. In the United States, ATCS has grown in popularity since 2008-2009. As vehicle-to-infrastructure (V2I) communication technologies have become more advanced, ATCS have evolved as described by the levels of intelligent decision-making in Figure 1. The ATCS Tool uses a meta-analysis of level 5 system deployment, specifically InSync, to estimate emissions reductions from ATCS. For further information on the meta-analysis, refer to the Emissions Data and Methodology Document for this tool. Examples of ATCS within some levels are also described below.

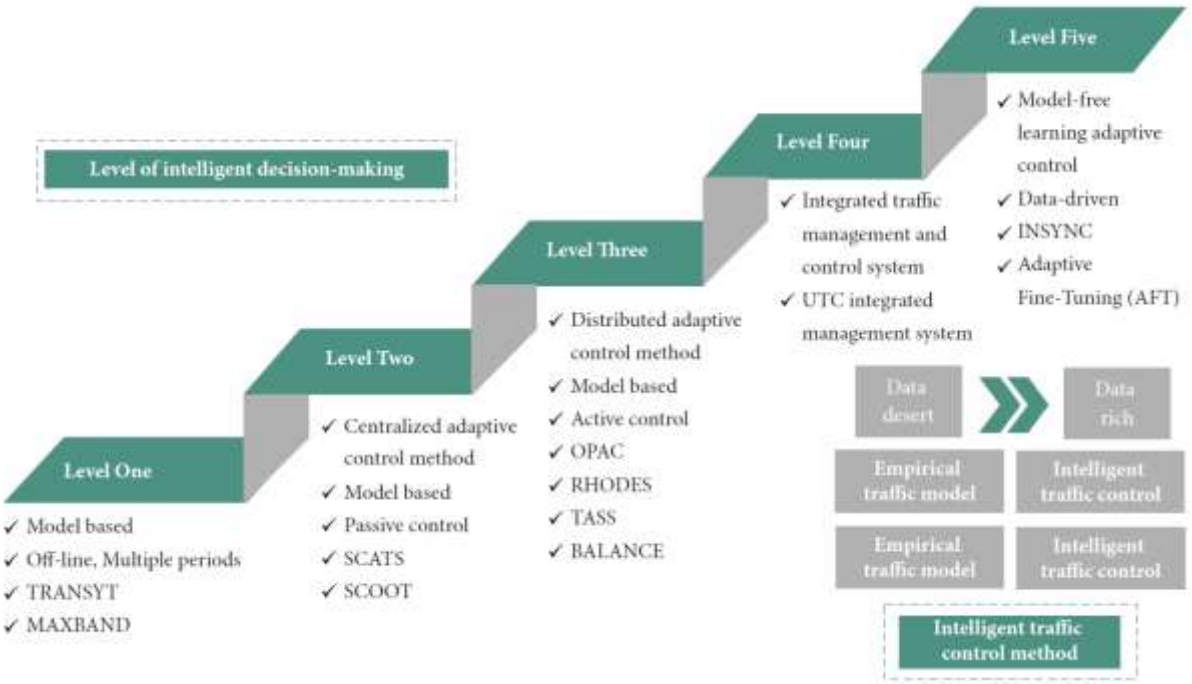


Figure 1. Levels of the adaptive traffic control system development process (Wang et. al 2018).

Level 1

First-generation ATCS are model-based and segment daily incoming traffic flow into distinct periods based on traffic demand (e.g., peak, non-peak). Within each period, the system optimizes the signal timing scheme to create a signal timing scheme library. The system can then choose the optimal offline scheme from the prepopulated library.

TRANSYT

TRANSYT is a software suite that first computes a baseline Performance Index (PI) from manually supplied traffic flows. The system then optimizes signal timings by minimizing the PI and creating "green waves".

MAXBAND

MAXBAND is available from the Federal Highway Administration. The FORTRAN IV computer program, which can handle up to 12 signals, determines optimal cycle time, offsets, speeds, and order of left turn phases using Land and Powell's MPCODE branch and bound algorithm.

Level 2

Unlike first-generation ATCS, second-generation ATCS dynamically adapt the signal timing scheme. Second-generation ATCS are model-based and use a passively controlled, centralized adaptive control method.

SCATS

The Sydney Coordinate Adaptive traffic System (SCATS) is one of the first ATCS and was developed by the New South Wales, Australia government in 1975. Push buttons that detect pedestrians and induction loops in the road that detect vehicles relay inputs to a traffic signal controller. Regional servers, which are managed by a central manger, process the input data, apply SCATS algorithms, and then communicate instructions back to the traffic signal controller to make decisions and ultimately control traffic signals.

SCOOT

Split Cycle and Offset Optimization Technique (SCOOT) was developed by Siemens Mobility. SCOOT continuously monitors traffic demand to optimize signal timings by minimizing delays and stops. Signal timing plans are updated every 3 seconds to allow rapid response. Signal timing changes are small to avoid large disturbances to overall traffic flow.

Level 3

Third-generation ATCS are similar to second-generation ATCS but use an actively controlled, distributed adaptive control method. Signal timing parameters are dynamically adjusted based on the current traffic flow at the intersection.

OPAC

Optimization Policies for Adaptive Control (OPAC) is an online computational strategy that operates using data provided by upstream link detectors. The system does not require a fixed cycle time and instead dynamically calculates signal timings based on real-time performance measures. OPAC was developed by the University of Lowell and sponsored by the U.S. Department of Transportation.

RHODES

RHODES was developed in 1990 by the University of Arizona. The system has a hierarchical structure and uses input from various upstream detectors to create signal timing plans. The goal of RHODES is to minimize cumulative delay.

Level 4

Fourth-generation ATCS are integrated traffic management and control systems. These systems are integrated with other ITS traffic management systems to assist local government with decision-making.

Level 5

Fifth-generation ATCS are data-driven and use model-free learning adaptive control. Adaptive fine-tuning (AFT) improves system performance by automating the need for manual tuning and calibration.

INSYNC

InSync, which is patented by Rhythm Engineering, are compatible with video detection and capable of accommodating connected vehicle operations. To date, InSync is deployed in 32 states and over 3,000 intersections which is more than all other similar systems combined.

Note

The preceding overview was based on the following sources:

Gartner, N. H., Tarnoff, P. J., & Andrews, C. M. (1991). Evaluation of Optimized Policies for Adaptive Control Strategy. *Transportation Research Record*, *1324*, 105–114.

In|Sync. (n.d.). Rhythm Engineering. Retrieved July 13, 2020, from https://trafficbot.rhythmtraffic.com/insync/

Little, J. D. C., Kelson, M. D., & Gartner, N. H. (1981). *MAXBAND : a versatile program for setting signals on arteries and triangular networks*.

National Academies of Sciences, Engineering, and Medicine. (2010). *Adaptive Traffic Control Systems: Domestic and Foreign State of Practice*. The National Academies Press. https://doi.org/10.17226/14364

SCATS and Intelligent Transport Systems. (n.d.). NSW Government. Retrieved July 13, 2020, from https://www.scats.nsw.gov.au/

SCOOT Adaptive Traffic Control. (n.d.). Siemens Mobility. Retrieved July 13, 2020, from https://www.mobility.siemens.com/us/en/portfolio/road/traffic-management/scoot-adaptive-traffic-control.html

Selinger, M., & Schmidt, L. (2010). *Adaptive traffic Control Systems in the United States: Updated Summary and Comparison*. HDR. http://cdnassets.hw.net/da/ad/6d673e3b4202b71314ab5eff3446/3675-adaptive-traffic-control-systems-in-the-united-states-updated-summary-and-comparison.pdf

TRANSYT. (n.d.). TRL Software. Retrieved July 13, 2020, from https://trlsoftware.com/products/junction-signal-design/transyt/#signal-optimisation

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Zhao, Y., & Tian, Z. (2012). An Overview of the Usage of Adaptive Signal Control System in the United States of America. *Applied Mechanics and Materials*, *178–181*, 2591–2598. https://doi.org/10.4028/www.scientific.net/AMM.178-181.2591