

APPENDIX: TRANSPORTATION AIR QUALITY SKETCH PLANNING TOOL



K



Enhancement of the Transportation Air Quality Sketch Planning Tool for the El Paso Region

Prepared for the El Paso MPO

Prepared under a grant from the Texas Commission on
Environmental Quality

November 2021

Texas A&M Transportation Institute

The preparation of this report was financed through grants from the State of Texas through the Texas Commission on Environmental Quality (TCEQ). The content, findings, opinions and conclusions are the work of the author(s) and do not necessarily represent findings, opinions or conclusions of the TCEQ.

ABOUT THIS REPORT

This work was performed by the Texas A&M Transportation Institute (TTI), for the El Paso Metropolitan Planning Organization (MPO), and was funded through a State and Local Air Quality Planning Program grant from the Texas Commission on Environmental Quality.

The principal investigator for this study is Tara Ramani. TTI contributors to this work include Tara Ramani, Rohit Jaikumar, Madhusudhan Venugopal, Jeremy Johnson, Xiaodan Xu, Apoorba Bibeka, Chaoyi Gu, and Kunal Bhatia. The TTI team gratefully acknowledges the input and support from the El Paso MPO, especially Dr. Salvador Gonzalez and Dr. Claudia Valles.

For further information about this work, please contact:

Tara Ramani, Ph.D, P.E.

Texas A&M Transportation Institute

Tel.: (979) 393-0688 Email: t-ramani@tti.tamu.edu

DISCLAIMER

The preparation of this report was financed through grants from the State of Texas through the Texas Commission on Environmental Quality (TCEQ). The content, findings, opinions and conclusions are the work of the author(s) and do not necessarily represent findings, opinions or conclusions of the TCEQ.

TABLE OF CONTENTS

About this Report	ii
Disclaimer	ii
Introduction.....	1
<i>Background and Objectives.....</i>	<i>1</i>
<i>Project Timeline and Milestones</i>	<i>2</i>
<i>Report Outline</i>	<i>2</i>
Overview of Tool Enhancements	3
<i>Key Updates from 2016 Version</i>	<i>3</i>
<i>Study Area and Scope.....</i>	<i>4</i>
System Design.....	5
<i>TDM Module.....</i>	<i>5</i>
<i>Non-TDM Module.....</i>	<i>6</i>
Computational Logic	8
<i>TDM Module.....</i>	<i>8</i>
Model Inputs.....	8
Emission Calculation	9
<i>Non-TDM Module.....</i>	<i>14</i>
Tool Overview and Use	15
<i>TDM Module.....</i>	<i>15</i>
<i>Non-TDM Module.....</i>	<i>24</i>
El Paso TDM Module Evaluation.....	29
Roadmap For Future Applications	31
Concluding Remarks.....	33
Appendix A-Quality Assurance Project Plan	34
Appendix B-Non-TDM Module Strategy Computations	45

LIST OF FIGURES

Figure 1. Study Area	5
Figure 2. TDM Module Workflow	10
Figure 3. TDM Module Algorithm Flowchart	13
Figure 4. Non-TDM Module Analysis Flow Chart	14
Figure 5. Overview of Sketch Planning Tool Modules	15
Figure 6. Annotated View of TDM Sketch Planning Tool Input Worksheet.....	17
Figure 7. Annotated View of the <i>View Results</i> Worksheet	19
Figure 8. Annotated View of the <i>Visualize Results</i> Worksheet.....	21
Figure 9. Annotated View of the <i>Adjustment Factors</i> Worksheet.....	22
Figure 10. Annotated View of Non-TDM Sketch Planning Tool Menu.	25
Figure 11. Annotated View of the <i>Bicycle and Pedestrian Facilities – New Facilities</i> Strategy Worksheet.	27
Figure 12 Overview of Methodology for Tool Evaluation.....	30
Figure 13 Comparison of SPT Results with the TTI Conformity Results.....	31

LIST OF TABLES

Table 1. Scope of TDM Module.....	6
Table 2. Strategies for Non-TDM Module	7
Table 3. TDM Module Inputs	8
Table 4. Time Period of the day in TDM	11
Table 5. Area Type Specifications in TDM.....	12
Table 6. Roadway Functional Classification of TDM	12

INTRODUCTION

BACKGROUND AND OBJECTIVES

The El Paso Transportation Air Quality Sketch Planning Tool was developed by the Texas A&M Transportation Institute (TTI) for the El Paso Metropolitan Planning Organization (MPO) in 2016, as part of the Rider 7 State and Local Air Quality Planning Program administered by the Texas Commission on Environmental Quality (TCEQ).

The existing tool was in the form of an Microsoft Excel®-spreadsheet that included two distinct modules: a travel demand model (TDM)-based module that uses TDM outputs to estimate network emissions for different scenarios, and a non-TDM module that estimates emissions benefits of individual projects/strategies based on user inputs (consistent with methodologies in the Texas Guide to Accepted Mobile Source Emissions Reduction Strategies [MOSERS]).

The TDM-based module of the existing tool estimates emissions at a regional level (i.e., for El Paso's regional road network). The tool uses data obtained from the El Paso MPO TDM, along with built-in emissions factors based on the EPA's Motor Vehicle Emissions Simulator (MOVES) model to estimate emissions. The pollutants estimated include ozone precursors (oxides of nitrogen and volatile organic compounds) and other contaminants, including particulate matter (PM₁₀ and PM_{2.5}), carbon monoxide (CO), and carbon dioxide. This module uses a similar emission estimation methodology to the formal transportation conformity process, with several simplifying assumptions to reduce computation time and complexity. The principal advantage of the tool is that it provides a relatively quick estimate of the impact of network improvements on regional emissions, enabling planners to assess the impacts of alternative build scenarios from an emissions perspective. The tool analyzed two alternative TDM scenarios (a base case and an alternative) and produced emissions results at the link, traffic analysis zone (TAZ), and district level. While it also estimates regional emissions, it has been emphasized to stakeholders that the TDM-based module should not be used for conformity analyses and do not have regulatory significance.

The non-TDM module, on the other hand, is used for the assessment of potential emissions reductions for individual strategies that are not modeled in the TDM. Thus, the results reported by this component of the tool are not comparable to emissions inventory results, but represent assessments of emissions reductions for a range of voluntary strategies that can be applied in the El Paso region.

The overall goal of the current project undertaken between June 2020 and November 2021 was to enhance and expand the existing Transportation Air Quality Sketch Planning Tool to increase its capabilities, flexibility, and level of detail in computations, and to meet the stated needs of the El Paso MPO.

PROJECT TIMELINE AND MILESTONES

The period of performance for this work was June 1, 2020, through November 15, 2021, and the work included seven distinct tasks, as follows:

- Task 1 – Project Initiation
- Task 2 – Computations and Data Assembly
- Task 3- Updates to the TDM Module
- Task 4- Updates to the non-TDM Module
- Task 5- User Testing
- Task 6 – Final Deliverables and Outreach
- Task 7 – Roadmap for Future Applications

Prior to initiation of work, a Quality Assurance Project Plan (QAPP) was developed, with approval of the QAPP received from TCEQ on June 19, 2020. Appendix A shows the finalized QAPP. TTI also maintained regular contact with the El Paso MPO during this project, submitting regular progress reports and providing informal updates via email. The MPO also worked with TTI to provide input on their TDM development and shared network and traffic analysis zone (TAZ) files. A total of six formal progress meetings were also held over the course of the project (via MS-Teams), including a demonstration of a draft version of the tool and user guide in September 2021, where the materials were shared with the El Paso MPO for user testing, and a final close-out meeting and demonstration in early November 2021.

REPORT OUTLINE

This report summarizes the work performed and key outputs from this project. Following this introductory section, the report covers the system design and computational logic of the tool, provides an overview of the tool use, discusses the evaluation of the results generated by the tool (including comparison of TDM module results with official conformity emissions inventories), and provides ideas for future applications to build on this work.

OVERVIEW OF TOOL ENHANCEMENTS

This section describes the system design and computational logic for the enhanced 2021 El Paso Transportation Air Quality Sketch Planning Tool (SPT). This version of the tool builds on the original spreadsheet based tool developed in 2016. The tool offers two major analytical components for different purposes, namely, a TDM-based module and a non-TDM based module. The TDM module is a spreadsheet-based planning tool that calculates emissions based on built-in emission factors and TDM outputs that serve as inputs to the tool. The non-TDM component can estimate emission benefits of individual projects/strategies that are not usually modeled in the TDM, based on user inputs along with built-in emissions rates.

KEY UPDATES FROM 2016 VERSION

In discussion with the El Paso MPO, it was determined that the existing Microsoft Excel®-spreadsheet based platform for the tool be retained. The tool uses built-in Visual Basic for application programming to perform the emission analysis, including automation of calculation and display of outputs. The El Paso MPO provided TTI with a list of desired enhancements/updates to the tool, which included:

- Inclusion of new emissions rates/different analysis years
- Ability to assess a single scenario or multiple scenarios in the TDM module
- Ability to handle updates to the travel demand model without the need to update the tool
- Adding in capability to estimate emissions for links in Mexico, ability to report results for "areas of interest" such as port-of-entry (POE) links, ozone, PM nonattainment areas, or CO maintenance areas
- Improved calculation times
- Refined emissions calculations to obtain results that are within 10% of a comparable emissions inventory
- Improved data visualization and reporting features

TTI investigated the feasibility of making the desired changes, and in discussion with the El Paso MPO prioritized and implemented several updates. The main updates/enhancements include the following:

- Development of the TDM and non-TDM based modules as separate spreadsheet tools, instead of in a single workbook.
- Inclusion of the following analysis years for the TDM module, at the El Paso MPO's request: 2017, 2020, 2022, 2027, 2030, 2032, 2040, 2045, 2050.

- On the TDM-based module, rather than directly uploading TDM output files, pre-formatted TDM outputs are pasted into the tool. This streamlines the tool and allows it to operate without requiring changes even if TDM field names or ordering change in the future.
- On the TDM module, various “areas of interest” are tagged on the basis of traffic analysis zones (TAZs). An initial list was populated based on the current TAZs and list of areas provided by the El Paso MPO, including the PM nonattainment area, POE area, and CO maintenance area. This allows for results to be displayed only for these areas of interest. Reporting of links by district and the accompanying visualization in the tool were also removed. Link-level emissions results are still available, and more dynamic results pages developed as well.
- A separate version of the TDM-based module was developed for use with the Ciudad Juarez TDM outputs being developed as part of binational modeling efforts. This module (termed as the “Mexico Module”) includes emissions rates from MOVES-Mexico and is a simplified version of the TDM-based module.
- Updated list of strategies, computations consistent with the MOSERS guide, and inclusion of cost-effectiveness calculations for strategies in the non-TDM module.

STUDY AREA AND SCOPE

While the study area is focused on El Paso (city and the county seat of El Paso County in the far western part of Texas), it extends into parts of Dona Ana and Otero County in New Mexico, and Ciudad Juárez in Mexico, due to the shared air basin. The general area is shown in Figure 1.

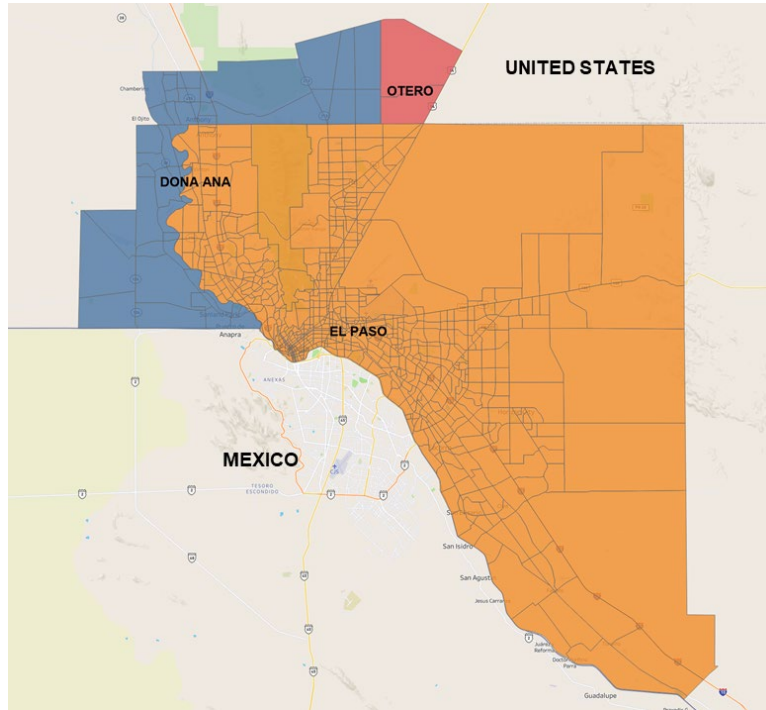


Figure 1. Study Area

TDM MODULE

The TDM module allows users to calculate emissions for various pollutants and assess the emissions impacts of various transportation planning scenarios generated from TDM (e.g., managed lane, new roadway facilities, transit improvements). This tool estimates critical air pollutants at link-level, for one or more TDM input scenarios. Table 1 summarizes the current scope of TDM module, such as the analysis year, season, time-of-day, and types of pollutant that can be supported in the analysis. A simplified, separate version of the TDM module was also developed for use with TDM outputs from the Ciudad Juarez network, which applies rates for Mexico. The computational logic and the system design remains mostly the same as the El Paso TDM module, with emission rates and the adjustment factors modified with Mexico specific numbers.

Table 1. Scope of TDM Module

Description	Input Parameter Values
MOVES Model Version	MOVES2014b
Functional Class of Roadways Considered	Urban Restricted, Rural Restricted, Urban Unrestricted and Rural Unrestricted
Speed	1-75 mph at 5 mph increments
Pollutant	Carbon Monoxide (CO) Particulate Matter – 10 Micrometer or less (PM ₁₀) Particulate Matter – 2.5 Micrometer or less (PM _{2.5}) Nitrogen Oxides (NO _x) Nitrogen Dioxide (NO ₂) Sulfur Dioxide (SO ₂) Volatile Organic Compounds (VOC) Carbon Dioxide equivalent (CO _{2e})
Time period	AM-Peak, PM-Peak, Off-Peak, Overnight
Seasons	Summer, Winter
Analysis Years	2017, 2020, 2022, 2027, 2030, 2032, 2040, 2045, 2050

NON-TDM MODULE

The non-TDM module was deployed as a separate workbook instead of having it together in the same workbook as the TDM module, as done in the previous version of the tool. This module estimates emission benefits for individual projects/strategies that are not traditionally modeled in TDM. The list of strategies for the updated non-TDM module were finalized in discussion with the El Paso MPO. They include four categories of strategies, described in Table 2. This module of the analysis tool allows for simplified calculations based on an emissions rate by vehicle type for selected analysis years, combined with user-input data on expected benefits. This tool includes MOVES2014b emissions rates for analysis years from 2020 through 2030. The pollutants included are oxides of nitrogen (NO_x) and volatile organic compounds (VOCs), particulate matter (PM₁₀ and PM_{2.5}), carbon monoxide (CO), and carbon dioxide equivalent (CO_{2e}).

Table 2. Strategies for Non-TDM Module

Strategy	Descriptions
Bicycle and Pedestrian Facilities	
	<p>This scenario considers emission reduction from reduced vehicle VMT with more people switching to biking and walking using bike and pedestrian facilities, either in the case of a facility improvement or for a new build facility. The emission estimation is generated based on the operating conditions of existing roadway facility (speed and AADT) and the VMT switched to non-motorized mode. Different adoption levels of bike and walk modes from empirical studies are used for different types of facilities, number of nearby attractions/destinations, and type of facility constructions (new build or improvement).</p>
Congestion Reduction & Traffic Flow Improvements	
	<p>This set of strategies assess reduction of congestion-related emissions from improving traffic operations and reduced travel delay. Specifically, the emission reduction benefits can be assessed for three types of congestion mitigation strategies: (1) intersection improvements, (2) signal coordination and (3) implementation of roundabout. The traffic flow characteristics before and after the improvements, such as traffic volume and speeds, will be used to quantify the emission reduction from those congestion mitigation strategies.</p>
Idle Reduction Zones	
	<p>This scenario quantifies the emission reduction related to idling activities within idling reduction zones designated for school buses or heavy-duty trucks. The emission reductions are estimated based on reduced idling hours per vehicle, number of vehicles within the zone, and potential emission increment due to additional engine start.</p>
Vehicle Replacement	
	<p>This strategy assesses the emission reduction benefits from replacing high-emitter vehicles with clean, new vehicles. The vehicle types considered in this analysis include heavy duty trucks, light duty vehicles, school buses and transit buses. It can also be used for assessing retrofits or engine repowering by entering the applicable emissions reductions expected for various pollutants. The emission calculation is based on user input data on the number of vehicles to be replaced, daily operations per vehicle (VMT and speed), and vehicle information before and after replacement (model year, vehicle type, and fuel type). Users are also required to enter the percentage reduction in emissions expected for each pollutant based on the emissions characteristics.</p>

COMPUTATIONAL LOGIC

This section provides details of the computational logic used in the SPT. The primary goal of this section is to help users understand the basis of the computations, including the model assumptions, inputs, outputs, and major computational steps.

TDM MODULE

The TDM module estimates emissions at the network level, based on computed link-level emissions. The computational approach behind the tool is similar to transportation conformity analysis, but this tool adopts several assumptions to simplify the workflow and allow faster assessment. Therefore, it cannot be used for any transportation conformity process directly and the results of this tool are for **internal sketch planning use only**. The following sub-sections will give a detailed outline of the computational process.

Model Inputs

The tool uses TDM inputs and built-in emission factors to estimate emission impacts at the transportation network level and aggregates results for the network, or for sub-areas of interest. Table 3 summarizes the major input and model parameters that are needed to run an analysis using the TDM-based module. The technical details related to specific attributes, such as area type and functional classifications, are also provided at the end of this section. For each scenario to be analyzed, TDM network data, as well as speed and flow data for four time periods need to be included.

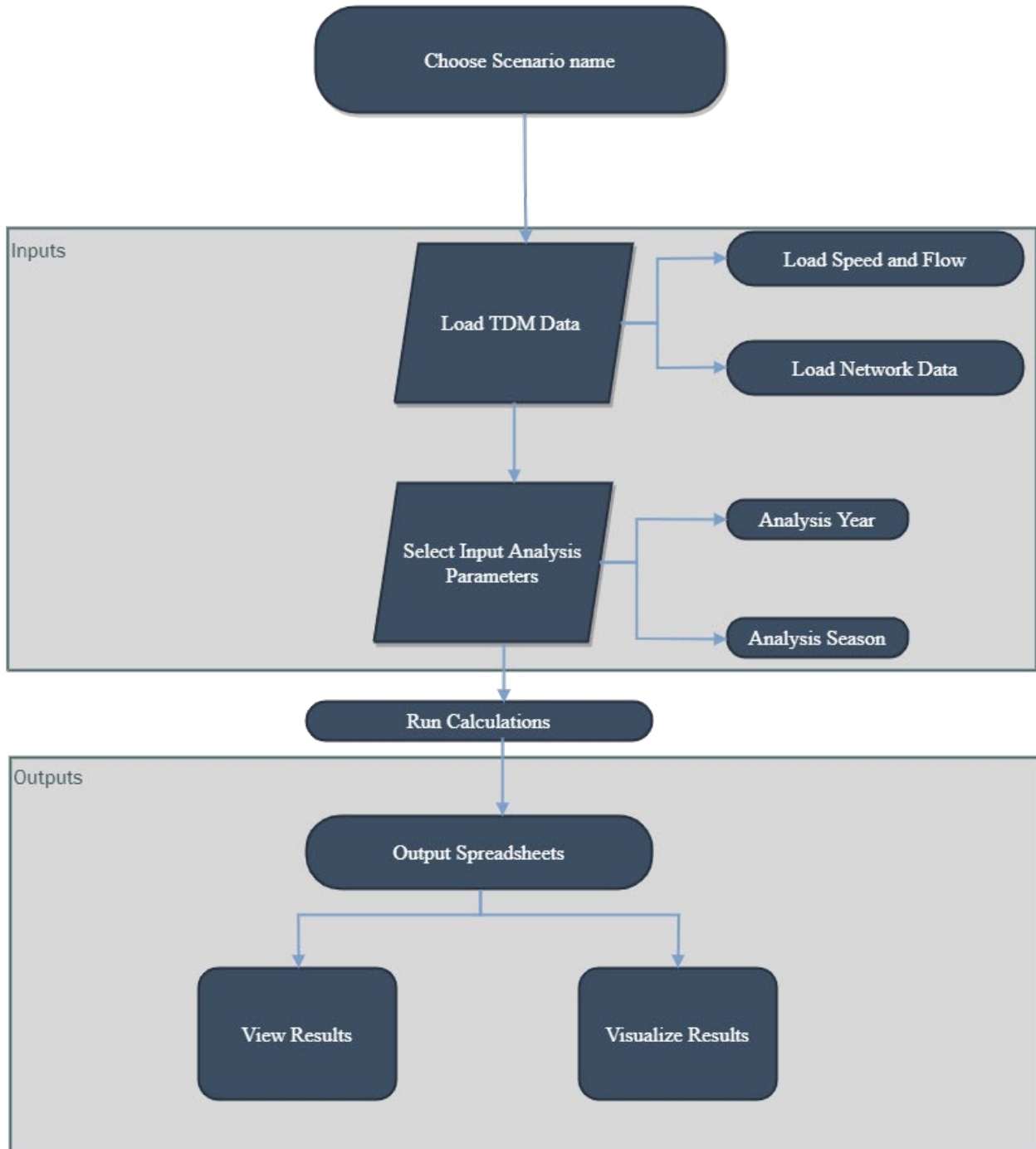
Table 3. TDM Module Inputs

Inputs from Travel Demand Model for Each Link	
Attributes	Description
Speed (mph)	Average speed of all throughput vehicles
Flow (veh/hour)	Vehicle throughput on the link during a given time interval
TAZ	Geographic sub areas within the study area
COUNTY	County Name
District	District Name
Area Type	Urban or rural

Functional Classification	Attribute defining roadways in terms of operational & performance classification
Analysis Parameters	
Attribute	Description
Time Period	Time Period of the day
Year	Forecast year (2020, 2022, 2027, 2030, 2032, 2040, 2045, 2050)
Season	Type of Season (Summer, Winter)
Emission Factor Lookup Table	
Attribute	Description
HPMS Factor	VMT adjustment factor based on traffic data collected from Highway Performance Measurement System (HPMS)
Summer Adjustment Factor	Seasonal VMT adjustment factor
Winter Adjustment Factor	Seasonal VMT adjustment factor
Pollutant Expansion Factors	Scaling factor for estimating total emissions from expanding the running emissions
AP42 Suspended Particle Factor (gram/mile)	Emission factor for calculating PM emissions from resuspended dust

Emission Calculation

The tool computes, analyses, and compares emissions based on TDM data and parameters selected as listed in Table 3 above. After the TDM output data are provided and the input parameters are selected, the tool will estimate the emissions by multiplying the vehicle activities with corresponding built-in emission rates, adjusted by various factors. The Figure 2 provides a high-level overview on major computational steps implemented in the TDM-based module, and a more detailed algorithm flowchart is provided in Figure 3.

TDM Based Sketch Planning Tool
Input/Output**Figure 2. TDM Module Workflow**

Emission estimates are performed using several equations listed below, with vehicle activity and emission factors serves as the major inputs. The tool uses built-in MOVES

definition for area and road type (see Table 4, Table 5 and Table 6) and interpolate emission factors for average operational speeds falling between two of the MOVES speed bin speeds. The emissions factors used for this tool are based on statewide Emissions Rate Lookup Tables developed for the Texas Department of Transportation. Technical documentation and details of computation of the rates is available in TxDOT’s Air Quality toolkit¹, with the emissions trends extrapolated where required for years not included in this dataset. As noted previously, the TDM-module adapted for Mexico uses running emissions rates from MOVES-Mexico². The link level emission is calculated based on adjusted VMT, aggregated emission factor and expansion factors. The equations required to aggregate emission factor using MOVES speed interpolation method is shown in the equation below.

$$EF_{Aggregated} = EF_{LowSpeed} - FAC_{inter} \times (EF_{LowSpeed} - EF_{HighSpeed}) \quad \dots Equation 1$$

$$EF_{intercept} = EF_{LowSpeed} - FAC_{intercept} \times (EF_{LowSpeed} - EF_{HighSpeed}) \quad \dots Equation 2$$

$$Emission_{link} = VMT_{link}(Adjusted) \times EF_{Aggregated} \times Expansion\ Factor \quad \dots Equation 3$$

Where,

$EF_{Aggregated}$ = Aggregated Emission Factor

$EF_{LowSpeed}$ = Built-in emission factor at low speed

$EF_{HighSpeed}$ = Built-in emission factor at high speed

VMT_{link} = Vehicle Miles Traveled for each link

$VMT_{link}(Adjusted)$ = Adjusted VMT_{link} for Aggregate Emission Factor and Expansion factor

Expansion Factor = Total emissions from conformity analysis /Running emissions from conformity analysis

For PM₁₀ and PM_{2.5} emissions, the resuspended dust is added to the emission inventory as well using EPA AP-42 method³. The resuspended road dust is calculated by multiplying AP-42 emission factors and adjusted VMT. After the emissions at link level are calculated, results are made available for reporting and aggregation.

Table 4. Time Period of the day in TDM

Period	Time
AM (Peak)	6:30 AM to 8:30 AM
PM (Peak)	2:30 PM to 6:30 PM
Mid-day (Off Peak)	8:30 AM to 2:30 PM
Over-night	6:30 PM to 6:30 AM

¹ <https://www.txdot.gov/inside-txdot/division/environmental/compliance-toolkits/air-quality.html>

² <https://www.epa.gov/sites/default/files/2021-03/documents/usaaid-inecc-2016-01-31.pdf>

³ [AP-42: Compilation of Air Emissions Factors | US EPA](#)

Table 5. Area Type Specifications in TDM

Area type number	Area type name	Density Range
1	Business district	>= 54
2	Urban intense	54-18
3	Urban central	18-6
4	Suburban	6-2
5	Rural	<2

Table 6. Roadway Functional Classification of TDM

Functional Class number	Functional Class name
1	Interstate
2	Other freeways or expressways
3	Other principal arterials
4	Minor arterials
5	Major collectors
6	Minor collectors
7	Local streets
20	Ramps

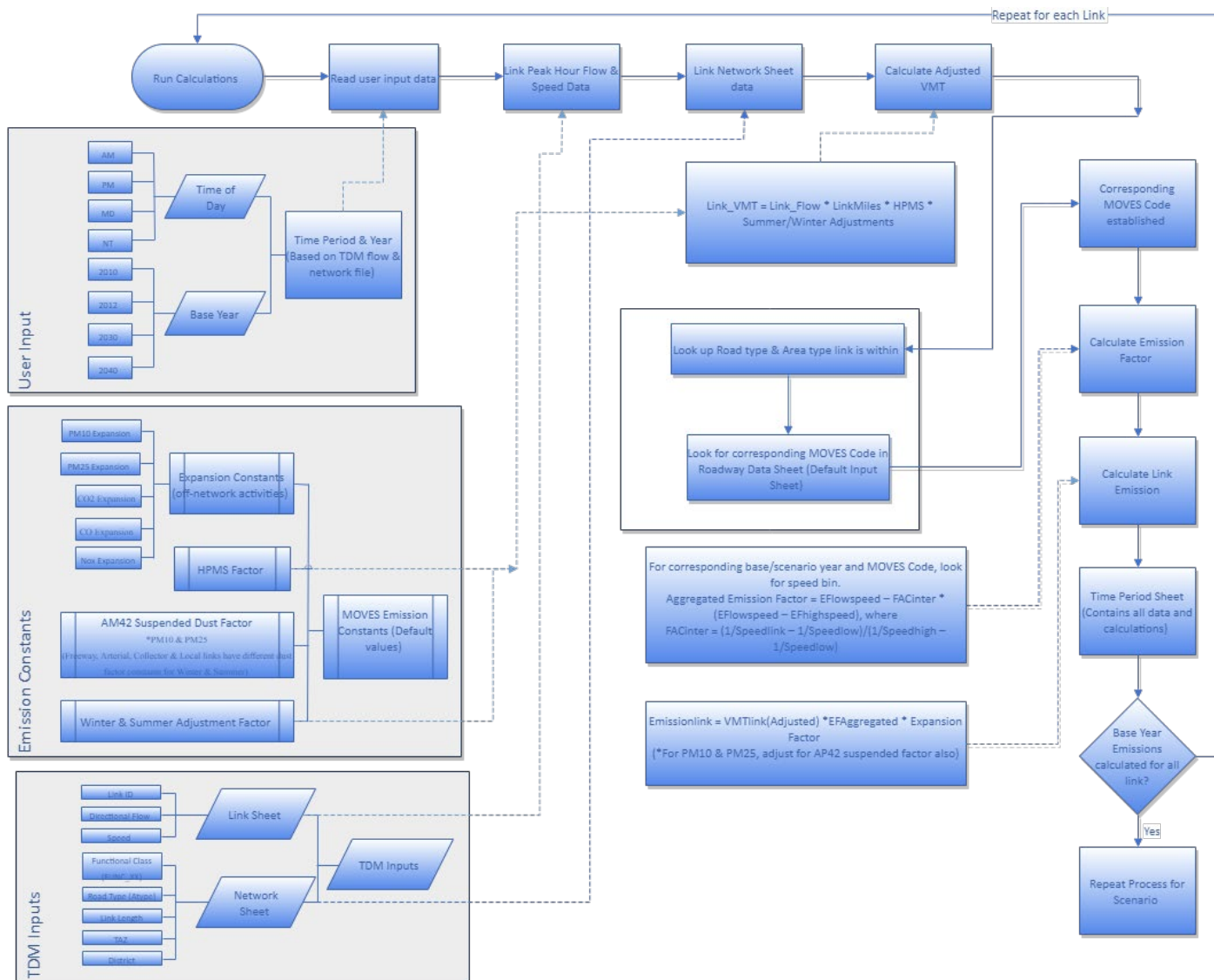


Figure 3. TDM Module Algorithm Flowchart

NON-TDM MODULE

For the strategies in the non-TDM module, the analytical approach varies based on the type of strategies, as shown in Figure 4. In the case of strategies that include a modification of traveler behavior, information will be needed on trip patterns, associated vehicle activity and traffic flow, which will result in estimated emissions impacts. In the case of system improvements, traffic flow changes can be used to compute emissions impacts, while for strategies focusing on vehicle and fuel technology changes (such as vehicle or engine replacements), emissions impacts can be computed based on the details about the number of the affected fleet and their overall operations. Since the non-TDM module includes a range of input parameters and detailed assumptions and calculations, they are provided in Appendix B. These methodologies are consistent with the MOSERS guide, and have been developed by TTI as part of work conducted for the Maricopa Association of Governments (MAG). As with the TDM-based module, emissions rates are based on MOVES2014b emissions rates for different vehicle types and activity types, depending on the strategy.

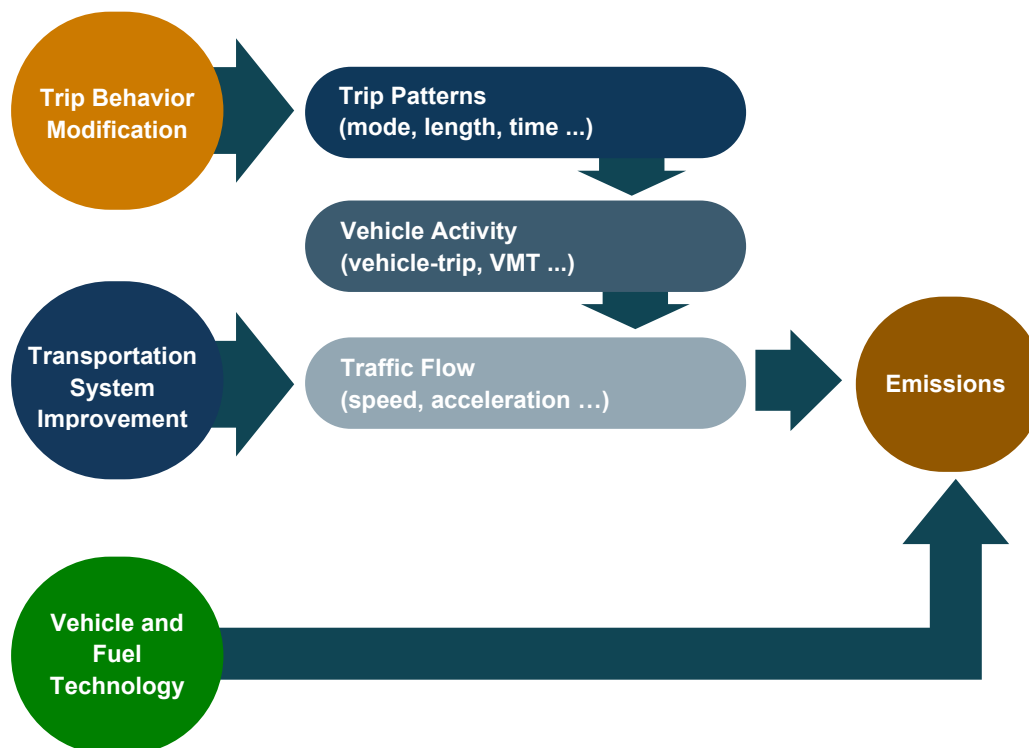


Figure 4. Non-TDM Module Analysis Flow Chart ⁴.

⁴ MOSERS Guide, available at the [Texas Air Quality Portal \(txaqportal.org\)](https://txaqportal.org)

TOOL OVERVIEW AND USE

As described previously, in the updated SPT, there are two distinct module types, the TDM-based module that is designed for use with the El Paso TDM (and a modified version for use with the TDM for Ciudad Juarez), and a non-TDM module. As with the older version of the tool, these are in a spreadsheet-based format, as an MS-Excel® workbook. The tool uses the built-in Visual Basic for applications programming to create the various functions of the tool, including automation of calculation processes and display of outputs. Figure 5 summarizes the key elements of each module. This section provides a brief overview of how to navigate and use the modules, and these are further detailed in the user guide accompanying this report.

TDM- Based Module	Non-TDM Module
<ul style="list-style-type: none"> • User inputs TDM outputs and selects analysis parameters • Emissions rates and computational methods are built in • Emissions results (link level emissions aggregated to the network) computed for one or more scenarios. Static results display and dynamic results exploration available. 	<ul style="list-style-type: none"> • User selects strategy of interest and enters strategy-specific input data • Emissions rates and computational methods are built in • Daily emissions reduction and cost-effectiveness of emissions reduction computed for the strategy

Figure 5. Overview of Sketch Planning Tool Modules

TDM MODULE

The TDM module and user interface has been developed to be user-friendly while protecting the integrity of the spreadsheet tool formulas and functions. The initial workbook consists of a set of visible worksheets:

- *Menu (also referred to as TDM Input worksheet)*
- *Adjustment Factors worksheet*
- *TAZ Groups worksheet*

- *View Results* worksheet
- *Visualize Results* worksheet

These visible worksheets are the ones that a user will require for navigating the tool, providing inputs, and viewing and exploring results. The tool includes several hidden worksheets that store information such as summer and winter emission rates, lookup lists for saving and storing user-supplied and default adjustment factors, three roadway data worksheets, and temporary worksheets for managing intermediate calculation results and tables. These worksheets are generally hidden from the user during normal tool operation but are required for the tool to function properly. Once the tool has been run, additional worksheets with the results from the tool will be added to the sheet by the tool automatically.

The *TDM Input* worksheet serves as the main menu and guides the user step-by-step through the input for the worksheet needed for running the module. A screen capture of the *TDM Input* worksheet is shown in Figure 6, with annotations corresponding to the paragraph numbers in the following section, which describes elements of the TDM Input worksheet and the functionality of the tool.

El Paso Metropolitan Planning Organization

Texas A&M Transportation Institute

Transportation Air Quality Sketch Planning Tool

TDM Module

Version 2.0
Release: November 2021

This module is customized to the El Paso Metropolitan Planning Organization’s travel demand model and contains local data and region-specific input parameters for use to assess network emissions. Follow Steps 1 through 3 to input the data and generate results. You can analyze multiple scenarios, and they will be identified in the results worksheet by the Scenario Name (1a.) specified for the run analysis. Please refer to the final report and user guide for additional information.

This is a sketch planning tool for planning purposes only. Results are not to be used for conformity or other regulatory purposes. The development of this tool was funded a State and Local Air Quality Planning Program grant from the Texas Commission on Environmental Quality

Step 1: Load TDM Data

1a Name:

1b Enter AM Speed and Flow Data
Enter PM Speed and Flow Data
Enter MD Speed and Flow Data
Enter NT Speed and Flow Data

Current Links in Dataset: 0 Reset

1c Enter TDM Network Data
Enter TDM Network Data

Current Links in Dataset: 0 Reset

Step 2: Select Analysis Year

2a Select Baseline Season: Summer

2b Select Baseline Analysis Year: 2017

Step 3: Run Data Analysis

Run Scenario

Menu Adjustment Factors View Results Visualize Results TazGroups

Figure 6. Annotated View of TDM Sketch Planning Tool Input Worksheet.

Step 1: Load TDM Data: The Load TDM Data section is where the user will input the desired data to run the tool (Item 1 in Figure 6). There are three main inputs required for the user to run the tool.

- a. The first input is the name of the scenario being tested. This is entered in Scenario Name text box at **1a** in Figure 6. The Scenario Name is limited to 13 characters, including spaces. The Scenario Name will be used as part of the worksheet identifier for the results.
- b. The next input required is the speed and volume information (assignment output) for each link in the network. Item **1b** in Figure 6 is where the user enters this data. The tool is programmed for manual entry of data.
- c. The travel demand model network data (which includes the description of each link) is added to the file using the buttons at **1c** in Figure 6.

Step 2: Choose Options from Dropdown Lists: Select a season (shown at **2a.**) and analysis year (**2b.**) from the two dropdown menus in Step 2 (Item 2 in Figure 6). The user can select either “Summer” or “Winter” as the season and from analysis years available in the tool.

Step 3: Run Analysis: Once all the data has been entered and the options available in dropdowns are selected, the “*Run Scenario*” button can be selected in Step 3 (Item 3 in Figure 6). This will initiate the tool to run based on the data and selected options.

After the scenario run is complete, a *View Results* worksheet will be opened by the tool through which user can explore results. The *View Results* and *Visualize Results* sheets can be used to explore results, as described below.

The *View Results* worksheet is the landing page for exploring the output of the tool after running scenarios. Figure 7 shows the annotated view of the *View Results* worksheet.

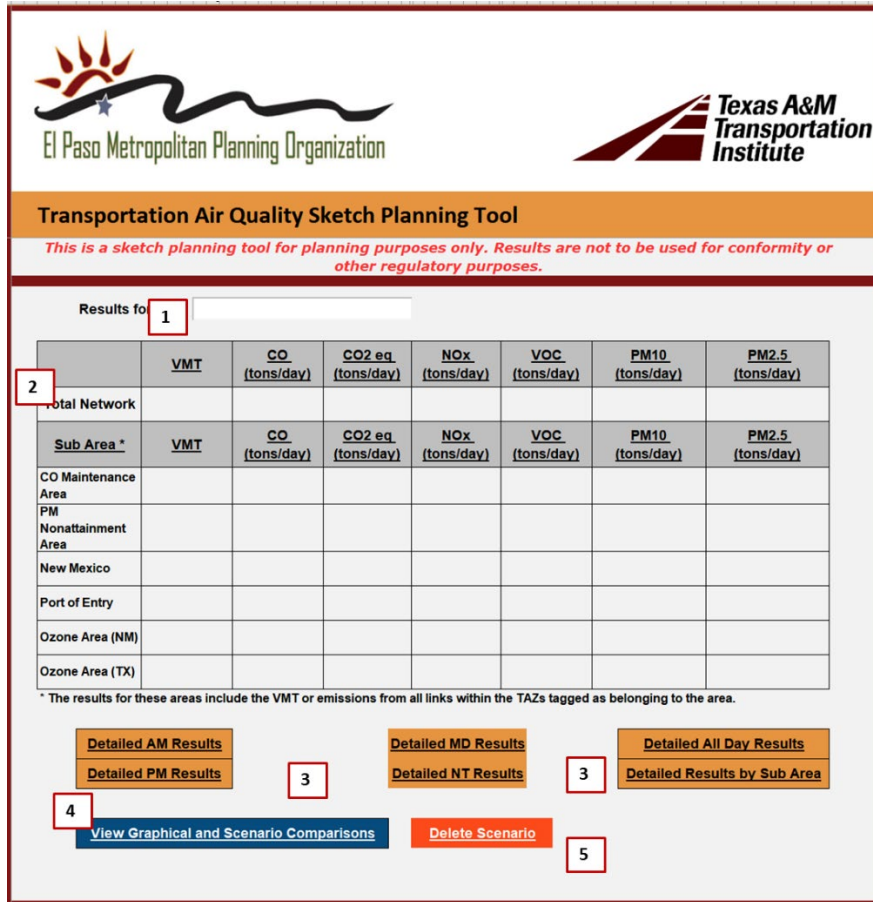


Figure 7. Annotated View of the View Results Worksheet

The different components of the sheet are annotated in the Figure 7 and described below

1. The area marked as [1] lets user select the scenario for which the output needs to be displayed. All the scenarios that have been previously run will be listed here automatically
2. The table in the area marked as [2] populates with the summarized results for the selected scenario based on the TAZ area type and the total network
3. Area marked as [3] of the *View Results* tab has the links to view detailed results based on the following parameters
 - a. Time of day (AM, PM, MD, NT)
 - b. All day

- c. By area type
- 4. Area marked as [4] links to the *Visualize Results* worksheet which lets user visualize the output and compare different scenarios.

The *Visualize Results* worksheet summarizes the link level results into graphical format for ease of access and understanding the results. The worksheet primarily consists of a pivot table and a pivot chart which updates dynamically based up on the user selection.

The following user interactions are developed for the convenience of the users as indicated in Figure 8.

1. Select the area type of TAZs for the visualization – following options are currently available (these are based on the *TAZ Groups* worksheet which includes the following predefined areas provided by the El Paso MPO)⁵
 - a. PM area
 - b. CO area
 - c. Ozone TX area
 - d. Ozone NM area
 - e. Port of Entry
 - f. New Mexico
2. Select Time Period of results to visualize – following options are available
 - a. Morning Peak
 - b. Evening Peak
 - c. Mid day
 - d. Overnight
 - e. All Day (sum of all time periods)
3. Select the pollutant of interest – following options are available
 - a. CO
 - b. CO_{2eq}
 - c. NO_x
 - d. VOC
 - e. PM₁₀
 - f. PM_{2.5}

⁵ The *TAZgroups* sheet has the currently defined area types received from the El Paso MPO. The sheet can be modified in the future in case there are changes in TAZs or area boundaries, or to add new areas.

- Select the scenarios for comparison – After running different scenarios this field will populate with the scenario names. User can select the number of scenarios to compare in the visualization

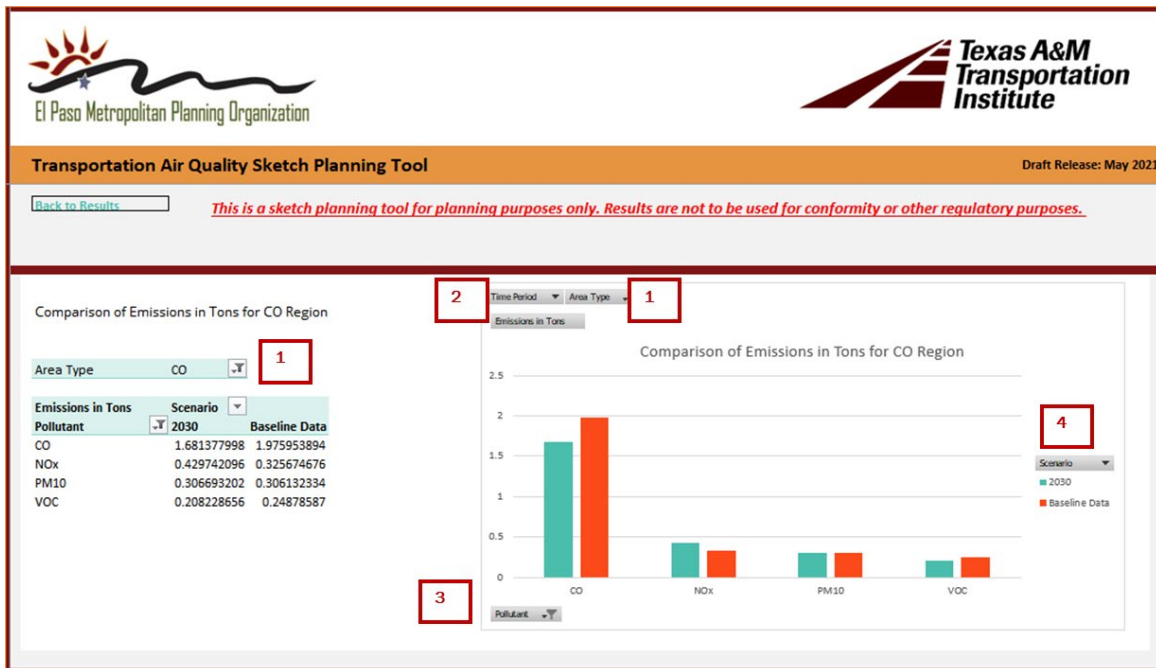


Figure 8. Annotated View of the Visualize Results Worksheet

In addition to the *TDM Input* worksheet, the *Adjustment Factors* worksheet also has inputs the user can modify (Figure 9). The purpose of this *Adjustment Factors* worksheet is to provide the user with a method of applying project-specific emission rate adjustment factors to the data calculations conducted in the *TDM Input* worksheet. The emission rates used in the *TDM Input* calculation are multiplied by the *Current Value* in the *Adjustment Factors* worksheet to adjust the emission rate calculations. The default adjustment factors were derived after calibration with the latest conformity emission inventory results for the years 2020, 2030 and 2040 (see the El Paso TDM Module Evaluation section of this report for more details). Since the factors are only available for three years for which an emissions inventory was available, the factors for other years were the same as the closest available ones.



Transportation Air Quality Sketch Planning Tool

Adjustment Factors

The TDM link-based emissions estimates require VMT estimates by hour and direction for each link in the TDM, as well as intrazonal VMT that is not accounted for in the TDMs. This process also requires that VMT be adjusted for HPMS consistency and to reflect estimated activity scenario levels, most commonly, a typical summer weekday.

VMT Factors	Description	1	Default	Current Value
HPMS Factor	The HPMS factor is a reconciliation of validation year TDM results with official validation year HPMS statistics (VMT), which is applied to future year model VMT.		0.964066834	0.964066834
Summer Adjustment Factor	Summer adjustment factors converts from future analysis year TDM average non-summer weekday traffic (ANSWT), or from historical year AADT, to reflect the summer and day-type of the emissions analysis scenario.		0.9603	0.9603
Winter Adjustment Factor	Winter adjustment factors converts from future analysis year TDM ANSWT, or from historical year AADT, to reflect the winter and day-type of the emissions analysis scenario.		0.99055	0.99055

Restore Defaults button overwrites the Current Value with the Default Value.

Restore Defaults

Emission Rate Factors

This tool estimates emissions by multiplying the emission factors from the table below with the TDM link-based activity estimates.

User-defined emission rate factors entered here (in the Current Value column) are assigned to the specific year and season selected in the dropdown list below. Emission rate factors in the table below will be applied based on the year and season selected.

2

Select Analysis Year	2040	
Select Season	Summer	
Emission Rate Factors	Default	Current Value
CO Expansion	1.618588606	1.618588606
CO2 Expansion	1.035668	1.035668
NOx Expansion	2.02677925	2.02677925
PM10 Expansion	1	1
PM25 Expansion	1.095849	1.095849
VOC Expansion	13.8439	13.8439
PM10 AP Freeway	0.026731105	0.026731105
PM10 AP Arterial	0.284822328	0.284822328
PM10 AP Collector	0.501520292	0.501520292
PM10 AP Local	0.871188607	0.871188607
PM25 AP Freeway	0.006023	0.006023
PM25 AP Arterial	0.069101	0.069101
PM25 AP Collector	0.121239	0.121239
PM25 AP Local	0.209795	0.209795

3

The Restore Defaults button restores only the currently-selected Analysis Year and Season combination. The Restore Defaults button does not affect other Analysis Year and Season combinations.

Restore Defaults

Figure 9. Annotated View of the Adjustment Factors Worksheet.

The Adjustment Factors worksheet includes a description of the worksheet followed by three user-input sections, which are described below. The paragraph numbers below correspond to the item numbers in the red circles in Figure 9. White cells are for user

input and are unlocked while light gray cells are fixed text or formulas and are locked to prevent editing.

- 1. VMT Factors:** The section of the worksheet is where the user can modify the adjustment factors that impact the VMT calculations in the sketch planning tool. There are three adjustment factors in this section—the HPMS factor and one adjustment factor for each the summer and winter seasons. The user can change the values in the *Current Value* column, which is the value the tool will use when run. Project- or area-specific HPMS, summer adjustment, and winter adjustment factors are entered in the *Current Value* column. These values are applied to the calculation conducted from the *TDM Input* worksheet. The *Restore Defaults* button at the bottom of the section will return the *Current Values* to the *Default* value.
- 2. Year and Season Options:** In this section, the user can select the year and season from the dropdown list to specify the specific year/season combination emission rate factors in the following table. Each year and season combination has a unique set of factors. Emission rate factors in the table will be applied based on the year and season selected in the scenario run calculations on the *TDM Input* worksheet.
- 3. Emission Rate Factors:** In this table, the user can change the emission rate factors for the selected year and season selected in dropdown lists (2). As with the VMT factors, the user can change values in the *Current Value* column, which are the values the tool will use when called by the selections in *TDM Inputs* worksheet. When the emission rate factors are changed and the workbook is saved, the values will be available for future calculations when the specific year and season combination is selected in the *TDM Inputs* worksheet.

The *Restore Defaults* button will return the *Current Values* to the default value for the selected analysis year and season. Clicking the *Restore Defaults* button will not affect the *Current Values* for the the combinations of analysis year and season that are not selected.

NON-TDM MODULE

The non-TDM module allows the user to calculate potential emissions reductions/benefits for implementing different transportation projects/strategies. This tool is customized to the El Paso region and contains local data and region-specific input parameters where available. The tool estimates criteria pollutant emissions ozone precursors (oxides of nitrogen [NO_x] and volatile organic compounds [VOC]), carbon monoxide (CO), carbon dioxide (CO₂), particulate matter (PM) pollutants at both 2.5 (PM_{2.5}) and 10 (PM₁₀) micron threshold levels. and greenhouse gases (CO_{2eq}).

The Non-TDM Sketch Planning Tool consists of:

- Menu,
- Multiple strategy worksheets, and
- Data and emission rate lookup worksheets.

The menu helps guide the user to the desired individual strategy worksheet (Figure 10). The tool's worksheets have been locked (without a password) to prevent accidental alterations or deletions of formulas. It is recommended to *keep the worksheets locked* while using the tool to avoid formula deletion or breaking formula links between the tool's worksheets.

**Transportation Air Quality Sketch Planning Tool
Non-TDM Module**

This module allows for the estimation of potential emissions reductions and their cost effectiveness for a range of transportation strategies, as listed below. This tool is customized to the El Paso region, and contains local data and region-specific input parameters where available, used in the emissions reduction estimates. The tool contains built-in-emissions rates and computations, and produces results based on user defined inputs. Please refer to the final report and user guide for additional information.

Menu

List of scenarios	Scenario Description
1. Bicycle and Pedestrian Projects 1.1 New Facilities 1.2 Improved Facilities	Reduce vehicle trips, VMT and emissions through bike and pedestrian facilities Add new facilities to replace vehicle trips and VMT with bike and walk Improve current facilities to further replace vehicle trips and VMT with bike and walk
2. Congestion Reduction & Traffic Flow Improvements 2.1 Intersection Improvements 2.2 Traffic Signal Coordination Projects 2.3 Roundabouts	Improve the operational efficiency and decrease congestion-related emissions Improve intersection functioning by addition of turning lanes Coordinate traffic signals to correspond with current traffic flows and reducing delays Reduce emissions by reducing idling time at intersection with roundabouts
3. Idle Reduction 3.1 Truck Idling Reduction Zone 3.2 School Zone Idling Reduction	Reduce vehicle emissions through idling restrictions Place idling time restrictions on trucks within the zone to reduce idling emissions Place idling time restrictions on school buses within the zone to reduce idling emissions
4. Vehicle Replacement (light-duty vehicle, trucks, and buses) 4.1 Vehicle Replacement	Replace existing vehicles with lower-emitting models Replace existing light-duty vehicles, trucks and buses with newer models

The development of this tool was funded a State and Local Air Quality Planning Program grant from the Texas Commission on Environmental Quality

Browser tabs: Menu, Bike Ped - New Facility, Bike Ped - Improved Facility, Intersection Improvements, Traffic Coordination, Roundabouts, Vehicle Replacement, Truck idle reduction, School bus idle reduction, Reference

5

Figure 10. Annotated View of Non-TDM Sketch Planning Tool Menu.

Following is a brief description of the numbered items on the menu worksheet (Figure 9).

1. A brief description of the tool,
2. Shortcut links (underlined text) to 8 emission reduction strategies grouped into 4 categories (Bicycle and Pedestrian Projects, Congestion Reduction & Traffic Flow Improvements, Idle Reduction, Vehicle Replacement),
3. Brief descriptions for the use and application of each emission reduction strategy and reference worksheet,
4. Tool version/release information, and
5. Direct access to strategies and reference worksheets through the worksheet tabs.

Clicking on any one of the shortcut links will take the user to the appropriate strategy or reference worksheet. As an alternate method to open an emission reduction strategy worksheet, the user may click directly on a worksheet tab along the bottom of the Excel window.

A typical emission reduction strategy worksheet using the *Bicycle and Pedestrian Facilities—New Facilities* worksheet as an example is shown in Figure 11. Each strategy worksheet is divided into six sections.

- Project Information,
- Project-Specific Inputs,
- Default Input Options and Constants,
- Emission Factors,
- Intermediate Results, and
- Outputs

In each strategy, **white** cells indicate cells where the user provides input. **Light gray** cells have formulas or protected values recommended not to be changed by typing directly into the cell. User input required for the strategy calculations is generally limited to the *Project-Specific Inputs* and *Default Input Options and Constants* sections of each strategy as shown in the example (items 4 and 5 of Figure 11).

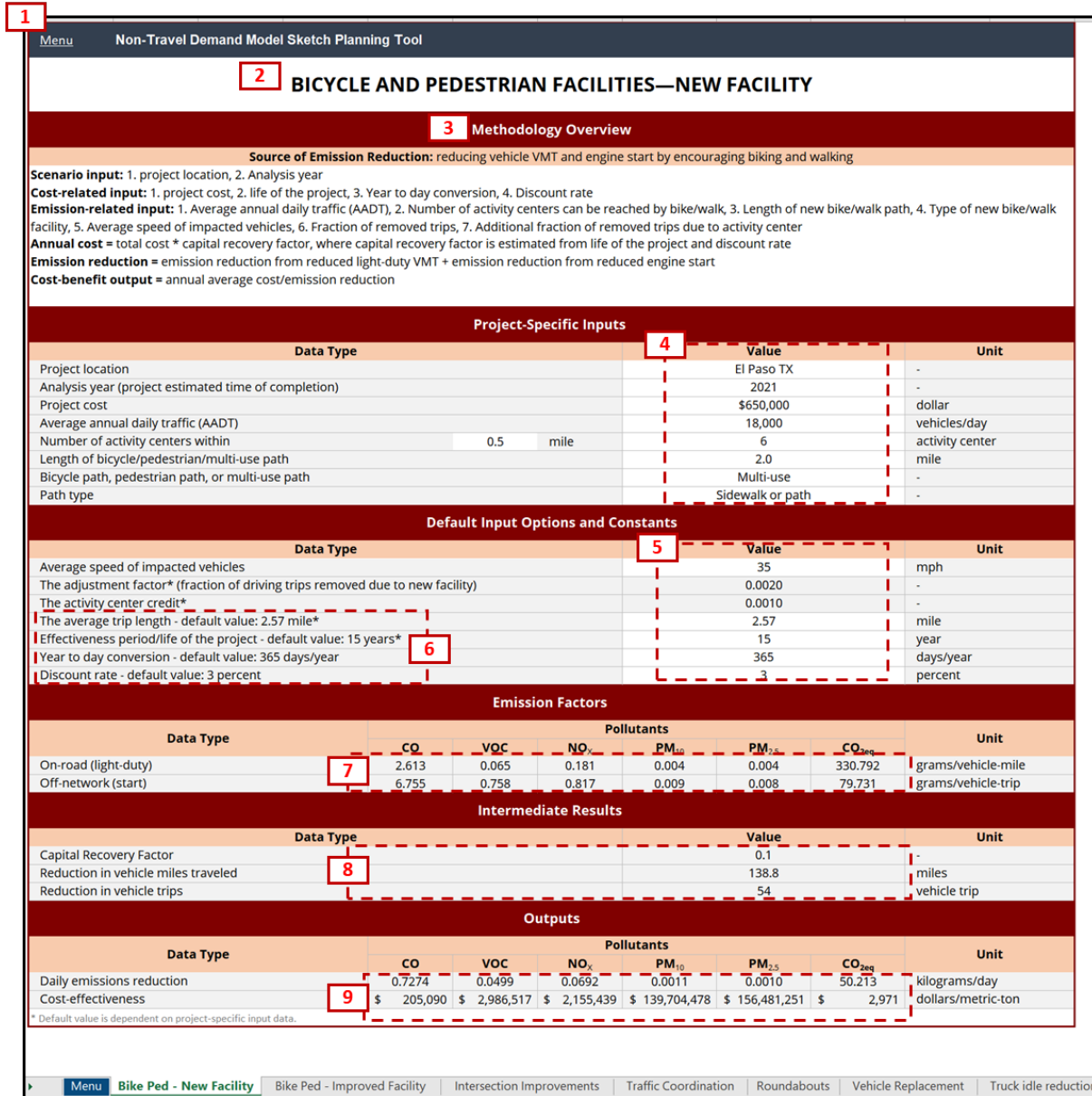


Figure 11. Annotated View of the Bicycle and Pedestrian Facilities – New Facilities Strategy Worksheet.

The sections of the strategy worksheets are briefly described below. The paragraph number below corresponds to the item annotation number in Figure 11.

1. Each emission strategy worksheet has a **menu shortcut** in the top left corner of the worksheet to return to the main menu.
2. The **strategy category and name** identify the individual non-TDM strategy,

The **Project Information** section provides users a place to input descriptive project-specific information by typing directly into the large white cell that makes up this section. The information in this portion of the worksheet is for reporting and documentation and is not used in the calculations. Completing this section is optional.

The **Project-Specific Inputs** section of each strategy worksheet requires project-specific input for the activity data calculations. White cells within this section indicate cells where the user provides direct input. The input section uses a drop-down list to the extent practicable. In two of the strategies (*Traffic Signal Coordination* and *ITS Corridor*), there are gray cells within the "Value" column of the *Project-Specific Input* section. The values in the gray cells are calculated based on other inputs selected by the user.

The **Default Input Options and Constants** section provides data that is used throughout the tool (i.e., input data that is not strategy-specific) such as workdays in the year or average auto occupancy values, as well as some strategy-specific default values. The parameters and constants used in this section can be viewed on the *Reference* worksheet and can be updated if needed. The gray cells within the "Value" column of the *Default Input Options and Constants* section contain formulas that are calculated based on other inputs selected by the user.

Project-specific data should be used when available; however, the **Default Input Options and Constants** section provides default values when they are needed. The recommended default value is provided within the description text of the "Data Type" column of the worksheet. In some cases, the default value is dependent on project-specific input or other default values as indicated by an asterisk. The values within either the "Data Type" column or the "Value" column may change/update as input and/or default values are changed.

The **Emission Factors** section provides the emission factors for each pollutant for the year selected by the user. The emission factors presented in the section are interpolated from the 2020 and 2030 base emission factors, which serve as the control emission factor values. This section contains formulas and is protected from editing. No user input is required in this section.

The **Intermediate Results** section provides interim calculations for various parameters in each strategy. This section contains formulas and is protected from editing. No user input is required in this section.

The **Outputs** section provides the total daily emission reduction (kilograms per day) and the cost-effectiveness of the strategy (dollars per metric ton) estimated by the tool. This section contains formulas and is protected from editing. No user input is required in this section.

Each strategy worksheet uses Excel's lookup formulas (xlookup, vlookup, or index and match) to find the appropriate values to populate the strategy worksheet. The lookup values, constants, and emission rates are in three data and lookup worksheets: *Reference*, *Rates*, and *Rates_Model_Year*. The next three figures show views of the data and lookup worksheets tabs. These worksheets can be accessed by selecting one of the worksheet tabs at the bottom of the Excel window or through the shortcut link on the menu page.

The first data worksheet is the *Reference* worksheet. As described earlier, this worksheet provides the constants and lookup values that are used throughout the tool that are not strategy-specific values. The values on this worksheet are referenced by formulas in the strategy worksheets. The default values may be changed on this worksheet; however, *any changes to this worksheet should be conducted with caution to prevent corrupting the strategy formulas that use these values*. Changes to the *Reference*, *Rates*, and *Rates_Model_Year* worksheets may also affect multiple strategy results. Like the rest of the tool, these worksheets have been locked (without a password) to prevent accidental alterations or deletions. It is recommended to keep the worksheets locked while using the tool to avoid formula deletion or breaking formula links between the tool's worksheets.

EL PASO TDM MODULE EVALUATION

One of the goals of the SPT enhancement activities was to ensure that the emissions results generated by the tool were comparable with official inventory results. However, it should be noted that this does not mean the tools' results can be used for regulatory purposes such as conformity or inventories. Also, given the range of inputs required to conduct an emissions inventory, it is also not feasible to develop a tool that produced results close to emission inventory results for all test cases. It was therefore agreed with the El Paso MPO that the tool would be evaluated and adjusted to ensure that it produces results within a 10% margin for selected test cases of emissions inventory outputs for key criteria pollutants. The evaluation was therefore done for multiple analysis years (2020, 2030 and 2040), multiple seasons (Summer and winter) and multiple pollutants (CO, NO_x, VOC and PM). The evaluation was repeated by adjusting

emission rates, VMT mix, age distribution used for emission aggregation and the algorithm of the tool till a discrepancy of less than 10% was achieved. These adjustment factors were then applied to the tool’s computations. The methodology followed for tool evaluation is shown in Figure 12.

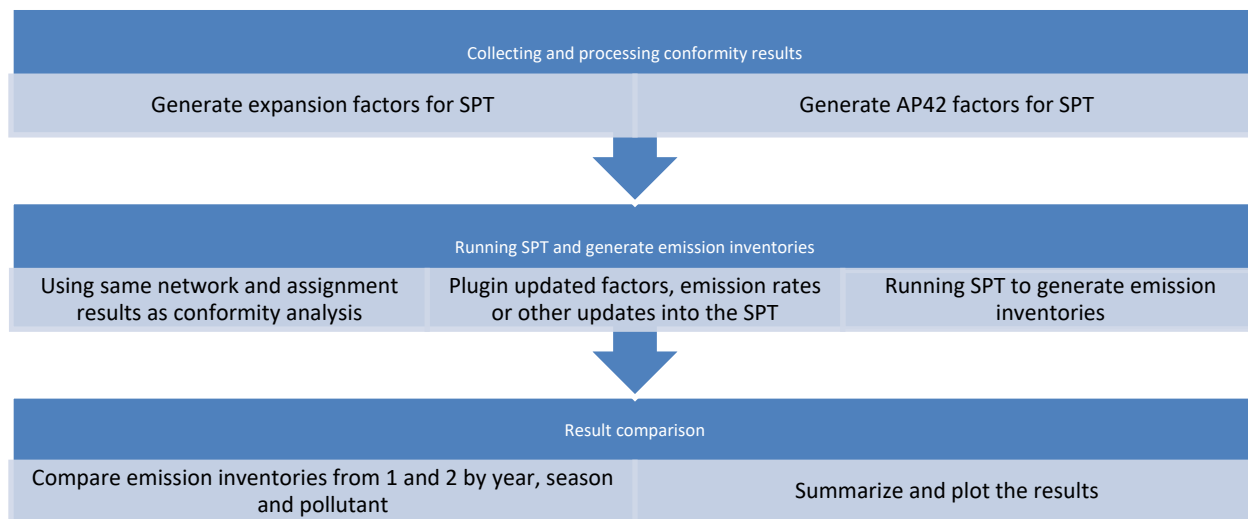


Figure 12 Overview of Methodology for Tool Evaluation

After repeating the process, TTI observed the SPT tool was estimating emissions with less than 10% discrepancy for all the analysis years, seasons and pollutants as shown in Figure 13. When new emissions inventories become available, adjustment factors within the tool may be changed to calibrate the results further.

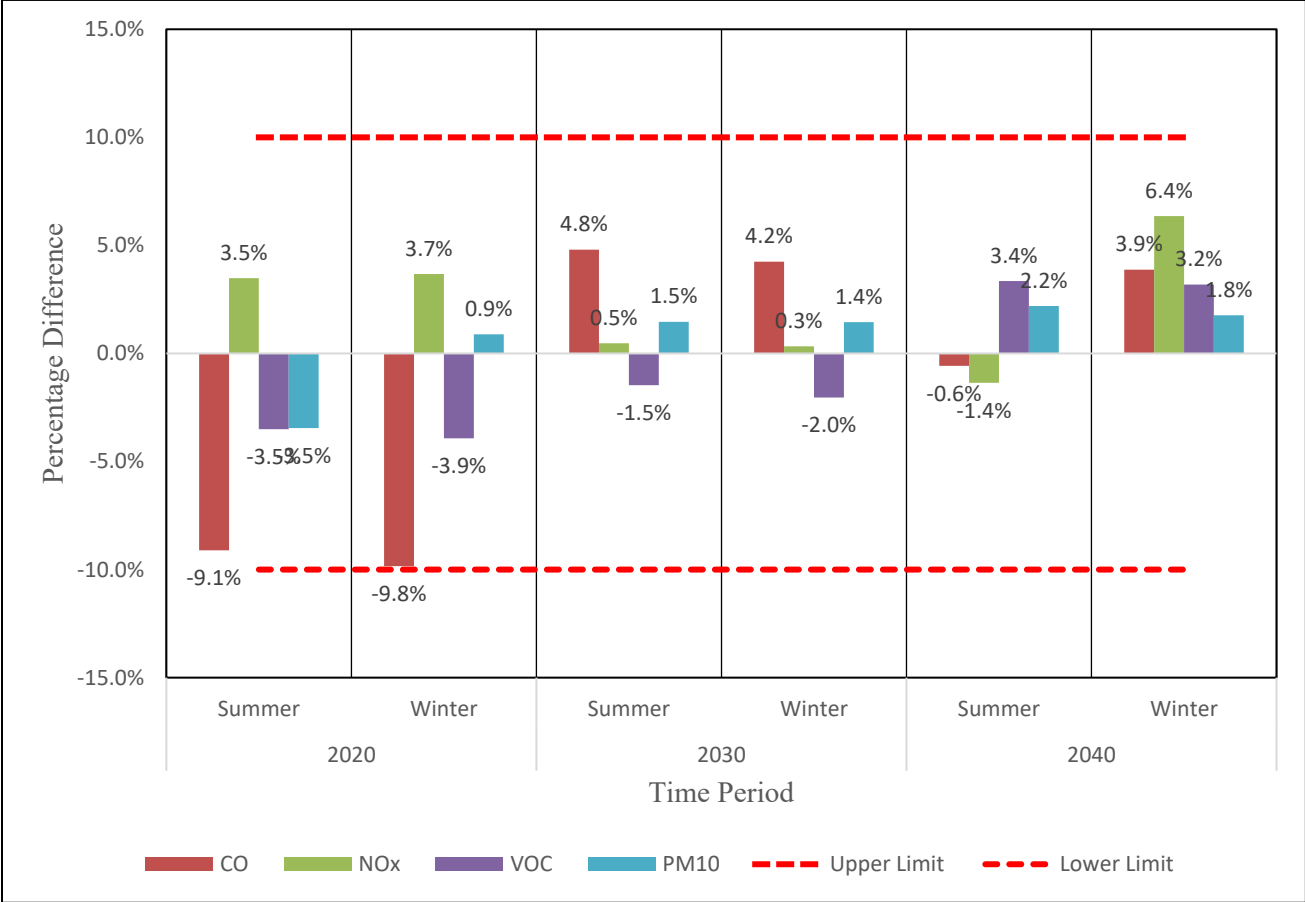


Figure 13 Comparison of SPT Results with the TTI Conformity Results

ROADMAP FOR FUTURE APPLICATIONS

This project to enhance the Transportation Air Quality Sketch Planning Tool has resulted in several enhancements to the tool originally developed in 2016. Most notably, for the main TDM evaluation component, the enhanced SPT runs faster, produces results that are closer to emissions inventory values, and provides results that can be navigated dynamically, with results available for special area types such as Port of Entry, or PM or CO nonattainment areas. The tool can also evaluate a single scenario or multiple scenarios, and the user input process has been adjusted to ensure that changes in the travel demand model fields do not affect the tools’ functioning.

There are several other avenues to further enhance the tool or create future applications that build on the current tool. These include the following, which can be considered by the El Paso MPO for the future:

1. **Other Platforms beyond MS-Excel** – The use of MS-Excel offers advantages in terms of not requiring installation of software, and being in a platform that is

familiar to all users. However, the MS-Excel format provides some constraints in terms of flexibility of programming the computations, and in displaying inputs and outputs. Future applications of the tool can be considered in other formats (such as a standalone application with a Graphical User Interface) to provide more flexibility and to enable more seamless interfacing with the travel demand model inputs without the need for post-processing, and to allow for enhanced use of the outputs with minimal post-processing.

- 2. Enhanced Mapping and Data Visualization Applications** – Whether the tool is retained in the existing Excel format, or developed in another platform, there are opportunities to use the tools' outputs for enhanced visualization and geospatial analysis. The use of platforms such as Tableau can help overlay results with other geospatial data and allow for more dynamic display and exploration of results.
- 3. Customized Port of Entry Analyses** – Currently, the tool uses TDM outputs, and cannot conduct more microscopic analyses of aspects such as the port of entry congestion and emissions impacts of the same. While the current tool can approximate the impact of idling at POE links by using near-zero speeds and comparing to speeds in the TDM. Future improvements can include a more enhanced sub-model for the POE area, allowing for impacts of creep idling and associated emissions to be better estimated.
- 4. Use of Traffic Data Sources Beyond TDM** – Similar to the previous point, evolving the tool to handle inputs from traffic data sources outside of the TDM can also help in the evaluation of projects that currently cannot be modeled in the TDM. Possible future enhancements to the tool can include the ability to model a sub-region of the network at a more microscopic level, taking into account traffic flow and other changes at a local level.
- 5. Integration with Air Quality and Health Modeling** – The tools outputs can also be used as inputs to regional air quality/dispersion models and used to support research- and public-outreach-based modeling applications. While having no regulatory or legal significance, applications such as these can help with scenario planning and stakeholder engagement related to transportation projects.

CONCLUDING REMARKS

This report summarizes the development of an enhanced Transportation Air Quality Sketch Planning Tool for the El Paso MPO. This tool includes a TDM- based and non-TDM based module for El Paso, as well as a modified version of the TDM module that can be used to assess networks in Ciudad Juarez, Mexico. This report focuses on the work performed, and the computational logic of the tools. User guides are accompanying the modules/tools that provide more detailed instructions to users. This iteration of the SPT represents significant advancements over the version developed in 2016. This report also describes additional ideas for further enhancement of the tool. Further, updates with the recently-released MOVES3 emissions model rates can be conducted in the future.

APPENDIX A-QUALITY ASSURANCE PROJECT PLAN

Quality Assurance Project Plan

Enhancements to the Transportation and Air Quality Sketch Planning Tool

June 2020, Revision 1.0

Submitted by:

Texas A&M Transportation Institute

QAPP Category Number: III

Type of Project: Software Development

PREPARED UNDER A GRANT FROM THE
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

The preparation of this report was funded through a grant from the State of Texas through the Texas Commission on Environmental Quality (TCEQ). The content, findings, opinions, and conclusions are the work of the author(s) and do not necessarily represent findings, opinions, and/or conclusions of the TCEQ.

QAPP Distribution

Title of Project: Enhancements to the Transportation and Air Quality Sketch Planning Tool

Distribution List

- Tara Ramani, Texas A&M Transportation Institute
- Madhu Venugopal, Texas A&M Transportation Institute
- Claudia Valles, El Paso Metropolitan Planning Organization
- Salvador Gonzalez Ayala, El Paso Metropolitan Planning Organization
- Chis Owen, Texas Commission on Environmental Quality

Table of Contents

1.0 Project Description and Objectives 4

1.1 Description of Software and Intended Applications 4

1.2 Project Purpose and Objectives 4

2.0 Organization and Responsibilities 5

2.1 Project Personnel and Responsibilities 5

2.1 Project Schedule and Key Milestones..... 5

3.0 Functional Requirements 6

3.1 Important Functions 6

3.2 Requirements for Functionality, External Interfaces, Performance, and Design Constraints .. 6

3.3 Computer Hardware and Operating System Requirements 7

4.0 System Design 7

4.1 Overview of System Design 7

4.2 Components and Subcomponents of Software Design 7

4.3 Rationale for Proposed Hardware and Software Tools..... 9

5.0 Implementation 9

5.1 System Development 9

5.2 System Verification and Validation 9

5.3 Managing Product Delivery/Release, Including Alpha and Beta Test Versions 10

5.4 Controlling, Documenting, and Archiving Software and Hardware 10

5.5 Archiving Software Used..... 10

6.0 Validation, Verification, and Testing..... 10

6.1 Testing Strategy and Procedures 10

6.2 Checking Correctness of Outputs 10

6.3 Product Conformity and User Expectations 10

7.0 Documentation, Maintenance, and User Support 10

7.1 Requirements for Project Documentation..... 10

7.2. Maintenance Support Procedures for Products or Data Distributed Outside NRMRL 11

7.3 Methods for Maintaining, Storing, Securing, and Documenting Controlled Product Versions
11

8.0 Reporting..... 11

8.1. Deliverables 11

8.2. Final Products 11

1.0 Project Description and Objectives

The Texas A&M Transportation Institute (TTI) has prepared this Level III Quality Assurance Project Plan (QAPP) for the El Paso Metropolitan Planning Organization (MPO) and the Texas Commission on Environment Quality (TCEQ), consistent with EPA National Risk Management Research Laboratory (NRMRL) for software development projects^{1,2}. Internal review and quality control measures consistent with these specified requirements along with appropriate audits or assessments of data and reporting of findings will be employed (including the minimum 10% audit of data quality as required for QA Category III projects). These include but are not limited to the elements outlined in this QAPP document. TTI is serving as a contractor to the El Paso MPO for the technical execution of this project.

1.1 Description of Software and Intended Applications

The El Paso Transportation Air Quality Sketch Planning Tool was developed by TTI in 2016, as part of the Rider 8/Rider 7 State and Local Air Quality Planning Program administered by TCEQ³. The tool is in the form of an MS-Excel spreadsheet that consists of two distinct modules: a travel demand model (TDM)-based module that uses TDM outputs to estimate network emissions for different scenarios, and a non-TDM component that estimates emissions benefits of individual projects/strategies based on user inputs. The MS-Excel spreadsheet sketch planning tool is therefore a standalone tool that does not require installation and will not require any additional supporting programs.

The TDM-based module of the tool is currently used by the MPO to estimate emissions at a regional level (i.e., for El Paso's regional road network). The tool uses data obtained from the El Paso MPO TDM, along with built-in emissions factors based on the EPA's Motor Vehicle Emissions Simulator (MOVES) model to estimate emissions. The pollutants estimated include ozone precursors (oxides of nitrogen and volatile organic compounds) and other pollutants, including particulate matter (PM10 and PM2.5), carbon monoxide, and carbon dioxide. This module uses a similar emission estimation methodology to the formal transportation conformity process, with several simplifying assumptions to reduce computation time and complexity. The TDM module of the tool estimates network emissions results. The non-TDM module, on the other hand, is used for the assessment of potential emissions reductions for individual strategies that are not modeled in the TDM.

1.2 Project Purpose and Objectives

The primary aim of this project is to update and improve the existing sketch planning tool to further increase its utility to the El Paso MPO. The El Paso MPO has provided TTI with a set of potential

¹ TCEQ Air Quality Research: Quality Assurance <https://www.tceq.texas.gov/airquality/airmod/project/quality-assurance>

² NRMRL QAPP Requirements for Software Development Projects <https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/qa/SoftwareQAPPNRMRL.pdf>

³ Texas A&M Transportation Institute, Development of a Transportation Air Quality Sketch Planning Tool for the El Paso Region, Prepared for the El Paso MPO, June 2016.

enhancements of interest, including improvements to the user experience and additional technical capabilities. The desired enhancements can be broadly categorized as follows:

On the TDM-Based Module

- Flexibility in computations and outputs
- Improved calculation times
- Refined calculations to get closer to official emissions inventory estimates
- Additional analysis years
- Inclusion of border crossing areas and Ciudad Juárez transportation links
- Functions for improved data visualization and reporting

On the non-TDM Module

- Ability to assess an expanded set of emissions control measures for on-road and non-road vehicles.

2.0 Organization and Responsibilities

2.1 Project Personnel and Responsibilities

All project activities will be conducted by TTI in cooperation with and oversight from the El Paso MPO and the TCEQ. Project personnel, including Quality Assurance (QA) and related responsibilities for each are described below.

- Dr. Tara Ramani of TTI will serve as the Principal Investigator and QA Officer for this project. She will be responsible for oversight on all project tasks, to ensure timely and satisfactory completion of the work and project deliverables.
- Mr. Madhu Venugopal of TTI will serve as the technical lead as well as QA Manager overseeing the development of the updated tool.
- Other TTI staff working on this project will include Dr. Josias Zietsman, Dr. Rafael Aldrete, Mr. Jeremy Johnson, Dr. Andrew Birt, Dr. Yanzhi “Ann” Xu, Dr. Xiaodan Xu, and Mr. Chaoyi Gu.
- Dr. Claudia Valles of the El Paso MPO will serve as the El Paso MPO project manager responsible for coordinating with TTI and TCEQ on the project.
- Chris Owen of the TCEQ will serve as the TCEQ Project Officer providing oversight of the project.

2.1 Project Schedule and Key Milestones

Key project tasks and milestones are listed in Table 1.

Table 1. Key Project Tasks and Milestones

Milestone/Deliverable	Due Date
QAPP Acceptable to TCEQ (Task 1)	On initiation of project
Computations and Data Assembly (Task 2)	End of 8 th month after the Project Initiation
TDM Module Development (Task 3)	End of 13 th month after Project Initiation
Non-TDM Module Development (Task 4)	End of 13 th month after Project Initiation
User Testing (Task 5)	End of 16 th month after Project Initiation
Final Deliverables and Outreach (Task 6)	End of 17 th month after Project Initiation
Roadmap for Future Applications (Task 7)	End of 17 th month after Project Initiation

3.0 Functional Requirements

3.1 Important Functions

The primary function of the tool is to estimate emissions based on user inputs pertaining to transportation conditions. The tool is in a spreadsheet-based format, as an MS-Excel[®] workbook. The tool uses the built-in Visual Basic macros for applications to create the various functions of the tool, including automation of calculation processes and display of outputs. For the TDM-based module, the tool will use outputs of the TDM to estimate emissions at a roadway network level, using built-in emissions rates. For the non-TDM module, each strategy has specific user inputs that are used to estimate emissions reductions using built-in emissions rates.

3.2 Requirements for Functionality, External Interfaces, Performance, and Design Constraints

The tool will include two standalone MS-Excel spreadsheets, for the TDM-based and non-TDM modules. No external interface is required for this tool to operate. The functional requirements of the tool are as follows:

TDM-Based Module:

- Ability to import pre-processed TDM outputs (link volume, link length, roadway type (functional class) and speed)
- Ability to select analysis parameters (analysis year, pollutants, time of day, etc.)
- Ability to estimate network emissions and emissions for subsets of the network on the basis of the TDM outputs and analysis parameters, using in-built emissions rates.

Non-TDM Module

- Ability to select an emissions control measure from a predetermined set of options
- Ability to enter user inputs required to estimate emissions impacts of the particular control measure
- Ability to estimate emissions impacts based on user input data and in-built emissions rates.

3.3 Computer Hardware and Operating System Requirements

The tool can be used on any computer with a 2010 or newer version of MS-Excel installed, though the computer memory and specifications may impact the tool’s runtime. It does not require any added hardware capacity or supporting software programs installed.

4.0 System Design

4.1 Overview of System Design

The tool (not software) will be developed as an MS-Excel spreadsheet, and will require no installation or software besides MS-Excel to operate. The basic system design is shown in Figure 1. Both modules of the tool rely on user inputs and built-in emissions rates and computations to generate outputs.

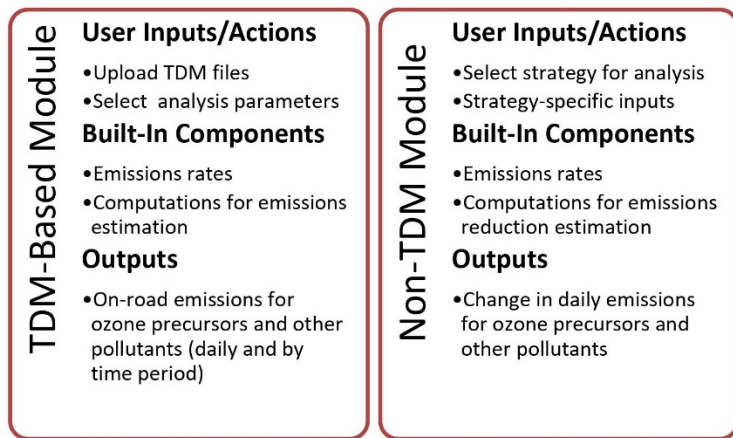


Figure 1. Tool Design

4.2 Components and Subcomponents of Software Design

Each module of the tool will be self-contained in individual sheets within a MS-Excel workbook. The key components required to meet functional requirements of each module are provided below:

TDM -based Module:

- User interface for data entry and file upload (mockup shown in Figure 2)
- Built-in emissions rates - emissions rates for use in the project will either be taken from TTI’s work for the TCEQ on development of statewide mobile source emissions inventories or generated by TTI using methods consistent with this work.
- Automated calculation processes
- Result display pages

The screenshot shows the 'TDM-Based Analysis' module of the 'Transportation Air Quality Sketch Planning Tool'. The interface is divided into four main steps:

- Step 1: Load Baseline Files**: Includes a 'Name:' text box and five file selection buttons: 'AM Flow File', 'PM Flow File', 'MD Flow File', 'NT Flow File', and 'Network File'.
- Step 2: Load Scenario Files**: Similar to Step 1, with a 'Name:' text box and the same five file selection buttons.
- Step 3: Select Analysis Parameters**: Contains three sub-sections:
 - Time Period(s)**: Radio buttons for 'AM', 'PM', 'Mid-Day', 'Night', and 'All Day'.
 - Pollutant(s)**: Checkboxes for 'CO', 'CO2', 'NOx', 'PM10', 'PM25', and 'VOC', all of which are checked.
 - Select Analysis Year**: A dropdown menu currently set to '2020'.
 - Season**: Radio buttons for 'Summer' and 'Winter', with 'Winter' selected.
- Step 4: Run Calculations**: Contains three buttons: 'Run Calculations', 'Clear Results Data', and 'Clear All Data'.

At the bottom, a navigation bar shows 'Menu', 'TDM Based Analysis' (highlighted), and 'Non-TDM Based Analysis'.

Figure 2. TDM Module User Interface Mockup

Non-TDM Module

- User interface for strategy selection and data entry (mockup shown in Figure 3)
- Built-in emissions rates - emissions rates for use in the project will either be taken from TTI's work for the TCEQ on development of statewide mobile source emissions inventories or generated by TTI using methods consistent with this work.
- Calculations that populate results directly in the spreadsheet.

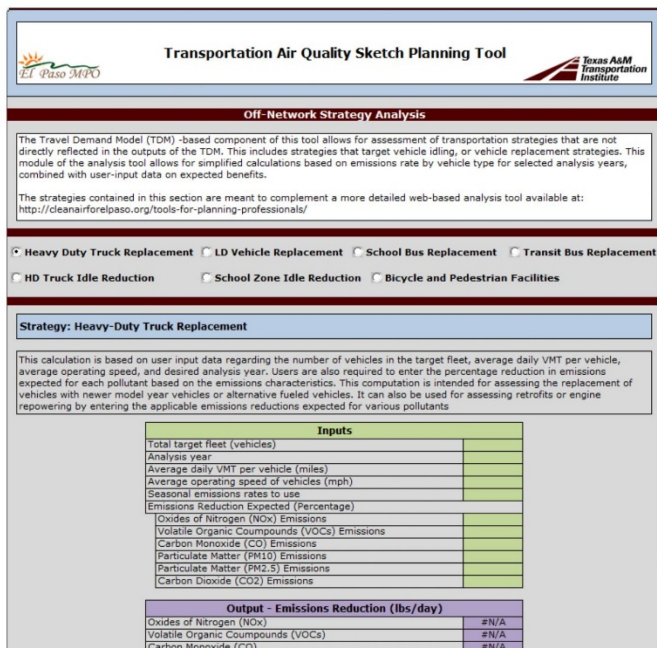


Figure 3. TDM Module User Interface Mockup

4.3 Rationale for Proposed Hardware and Software Tools

The MS-Excel format for the tool was previously identified as the preferred platform by the El Paso MPO. Since this project is an update of the same tool, the existing structure and platform is being retained. This will also ensure that no additional software or installation procedures need to be performed for this tool to function.

5.0 Implementation

5.1 System Development

This subsection does not apply to this project, as it involves development of a tool and not software. MS Excel is preinstalled as part of the MS Office package. The aim of this project is to use the same working system as the basis for updates and enhancements, to meet additional computational needs.

5.2 System Verification and Validation

Since the existing MS Excel platform will used, functionality, external interfaces, performance, and design constraints will not require verification and validation. The verification and validation

of the functional requirements will be assessed by the ability of the tool to estimate emissions based on appropriate input data.

5.3 Managing Product Delivery/Release, Including Alpha and Beta Test Versions

This project will develop a spreadsheet-based tool, not software. Therefore, this subsection does not apply.

5.4 Controlling, Documenting, and Archiving Software and Hardware

This project will develop a spreadsheet-based tool, not software. Therefore, this subsection does not apply.

5.5 Archiving Software Used

This project will develop a spreadsheet-based tool, not software. Therefore, this subsection does not apply.

6.0 Validation, Verification, and Testing

6.1 Testing Strategy and Procedures

Each component of the TDM and non-TDM modules of the tool will be tested for a range of data inputs to ensure functionality and appropriate results for valid data inputs, and for error messages to be displayed in the case of invalid inputs.

6.2 Checking Correctness of Outputs

TTI will thoroughly QA/QC all computations, validation of model inputs, checks for data entry errors, etc. This effort will cover and surpass the project requirement of a 10 percent audit of data quality and will be documented in the final report. Correctness of the outputs will be assessed relative to comparable emissions inventories (in the case of the TDM-based module) and relative to the Texas Guide for Mobile Source Emissions Reduction Strategies (MOSERS) analyses or other tools to ensure that the results are of similar order of magnitude and within expected ranges. All such comparisons will be reported.

6.3 Product Conformity and User Expectations

The tool will be determined as fulfilling its intended use after thorough analysis of the results in relation to emissions inventory outputs and outputs of other comparable documented emissions analyses, followed by approval/concurrence of the El Paso MPO.

7.0 Documentation, Maintenance, and User Support

7.1 Requirements for Project Documentation

A detailed user manual will be developed to accompany the tool. The computation methods as well as code embedded in the tool will be accessible to users within the tool itself.

7.2. Maintenance Support Procedures for Products or Data Distributed Outside NRMRL

This project will develop a tool, not software, which is intended for the sole use of the El Paso MPO. Therefore, this subsection does not apply.

7.3 Methods for Maintaining, Storing, Securing, and Documenting Controlled Product Versions

The tool will be password protected to avoid any unintended changes to built-in data and computations, and one final version will be submitted to the sponsor upon completion of the project. The tool will not be designed to have automated updates for any future versions. Therefore other elements of this section do not apply.

8.0 Reporting

8.1. Deliverables

The deliverables that will be produced include:

- Updated TDM-based module of the Transportation Air Quality Sketch Planning Tool
- Updated non-TDM module of the Transportation Air Quality Sketch Planning Tool
- Updated user manual describing the use of the tool, as well as computational logic
- Technical report summarizing work performed
- Roadmap for future sketch planning tool applications

8.2. Final Products

Expected final products of this work are the TDM-based module and non-TDM module of the sketch planning tool, as well as an updated user manual. Documents and data related to the project will be kept at TTI's offices for a minimum of 3 years on TTI servers. Copies of report and relevant data will also be supplied to the El Paso MPO and the TCEQ for their records. If TTI decides to terminate the records after the expiration of this period, the El Paso MPO and the TCEQ will be informed of this decision and there will be an opportunity for transferring all public records to the sponsor. Sufficient documentation will be retained to ensure that any analyses/computations conducted during the project can be replicated with the available information.

APPENDIX B-NON-TDM MODULE STRATEGY COMPUTATIONS

1.0 BICYCLE AND PEDESTRIAN FACILITIES

Bicycle facilities have the potential to reduce commutes and other nonrecreational trips. Bicycle paths are facilities that are physically separated from motor vehicle traffic. Bicycle lanes are striped for the preferential or exclusive use of bicycles. Agencies can install bicycle detection systems that give preferential treatment to bicycles on roadways. CO, VOC, NO_x, PM₁₀, and PM_{2.5} emission reductions occur when bicycle trips replace SOV trips.

Pedestrian facilities provide or improve pedestrian access. Emissions are reduced when vehicle trips are replaced by walking. The CO, VOC, NO_x, PM₁₀, and PM_{2.5} emission factors are calculated for the implementation year of the project. The project life for bicycle lanes on roads or shoulders will be 20 years; for sidewalks, bicycle paths, and pedestrian paths, 30 years; and for overpasses and underpasses, 50 years.

The included bicycle and pedestrian facilities sub-strategies are as follows:

- New Facility.
- Improved Facility:

1.1 New Bicycle and Pedestrian Facilities—New Facility

User-Defined Inputs and Constants

The methodology requires the set of project-specific inputs presented in Table B1. The available defaults provided for these projects are shown in Table B2.

Table B1. New Bicycle and Pedestrian Project User-Defined Inputs

Input	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> • Select the project location from the project location list.

Input	Units	Input Guidance
Analysis Year		<ul style="list-style-type: none"> Select the analysis year from the list
Project cost	dollars	<ul style="list-style-type: none"> Enter the estimated cost for the project.
Average annual daily traffic (AADT)	vehicles	<ul style="list-style-type: none"> Enter the AADT on the nearest parallel arterial.
Number of activity centers within ¼ mile or ½ mile of the bicycle/pedestrian project	activity centers	<ul style="list-style-type: none"> Enter the number of activity centers. Examples include a bank, church, hospital, health care facility, light-rail station, park-and-ride lot, office park, post office, public library, shopping area, grocery store, university, or junior college.
Length of bicycle/pedestrian path	miles	<ul style="list-style-type: none"> Enter the length of the bicycle, pedestrian, or multi-use path. For a bridge/underpass, the path length of the bridge/ overpass will be twice if it is bi-directional as compared to if it is unidirectional.
Bicycle path or pedestrian path or multi-use path	-	<ul style="list-style-type: none"> Select the path usage from the path usage list.
Path type	-	<ul style="list-style-type: none"> Select the path type from the path type list.

Table B2. Bicycle and Pedestrian Project Default Input Options and Constants*⁶

Parameter	Value
Average trip speed of impacted vehicle (mph)	40
The adjustment factor	See Table 9
The activity center credit	See Table 9
The average trip length (miles)	Bicycle- 4.64 Pedestrian- 0.50 Multiuse- 2.57

⁶ Recommended by MAG Staff based on the analysis of travel demand model.

Parameter	Value
Effectiveness period/life of the project (years)	50 years for overpass or underpass, 30 for sidewalk or path, 20 for the rest
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

The number of vehicles that can be replaced by bicycle or pedestrian (bicycle/pedestrian) trips are estimated based on the AADT on the adjacent or nearest parallel arterial to the bicycle/pedestrian facility; the weekday AADT is provided by the entity requesting funding for the project. The maximum allowable AADT is 30,000 vehicle trips per weekday. The vehicles reduced are calculated by multiplying the AADT by the sum of the adjustment factor (A) and the activity center credit (C).

The adjustment factor (A) in Table B3 is dependent upon the length of the bicycle/pedestrian project and the AADT on the road parallel to the bicycle/pedestrian project. Given the relative importance of bridges and underpasses that connect bicycle/pedestrian paths, the adjustment factor used for bridges and underpasses is based on the sum of the lengths of the two paths connected.

The usefulness of a bicycle/pedestrian facility is also dependent upon its location. Usage estimates for bicycle/pedestrian facilities take into consideration the number of activity centers near the proposed facility. The credit (C) for activity centers located along a bicycle/pedestrian facility is shown in Table B4.

Table B3. Adjustment Factors (Adapted from CARB, 2005)⁷

AADT	Length of Project (One Direction)	Adjustment Factor (A)
AADT ≤ 12,000 vehicles per day	≤ 1 mile	0.0019
	> 1 mile and ≤ 2 miles	0.0029
	> 2 miles	0.0038
12,000 < AADT ≤ 24,000 vehicles per day	≤ 1 mile	0.0014
	> 1 mile and ≤ 2 miles	0.002
	> 2 miles	0.0027

⁷ CARB, 2005. Methods to Find the Cost Effectiveness of Funding Air Quality Projects. Prepared by the California Air Resources Board. May 2005.

AADT > 24,000 vehicles per day	<= 1 mile	0.001
	> 1 mile and <= 2 miles	0.0014
	> 2 miles	0.0019

Table B4. Activity Center Credits (Adapted from CARB, 2005) ⁷

Number of Activity Centers	Activity Center Credit (C)	
	Within 0.5 mile	Within 0.25 mile
At least three	0.0005	0.001
More than three but less than seven	0.001	0.002
Seven or more	0.0015	0.003

Note: Examples of activity centers: a bank, church, hospital, health care facility, park-and-ride lot, office park, post office, public library, shopping area or grocery store, schools, university, or junior college.

The vehicle miles of travel reduced (VMTR) by bicycle/pedestrian facilities is estimated by multiplying the vehicles reduced by the average trip length. Consistent with the 2011 MAG CMAQ methodologies, a pedestrian trip length of 0.50 miles⁸ and an average bicycle trip length of 4.64 miles are assumed. For multi-use paths, it is assumed that half of the trips are bicycle and half are pedestrian. Therefore, an average trip length of 2.57 miles is applied for multi-use paths.

The MOVES model was run to estimate CO, VOC, NO_x, PM₁₀, and PM_{2.5} emission factors for light-duty vehicles (ONF_{CO} , ONF_{VOC} , ONF_{NO_x} , $ONF_{PM_{10}}$, and $ONF_{PM_{2.5}}$), assuming a speed of 40 mph. The off-network emission factors (OFF) in grams per vehicle per start (OFF_{CO} , OFF_{VOC} , OFF_{NO_x} , $OFF_{PM_{10}}$, and $OFF_{PM_{2.5}}$) are multiplied by the number of vehicle trips reduced (VTR) by bicycle/pedestrian trips. The arterial (Road Types 3 and 5) emission factors in grams per mile (ARF_{CO} , ARF_{VOC} , ARF_{NO_x} , $ARF_{PM_{10}}$, $ARF_{PM_{2.5}}$) are multiplied by the VMTR by the bicycle/pedestrian trips.

For PM, the paved road emission factor for arterials ($PEF_{PM_{10}}$ & $PEF_{PM_{2.5}}$) is added to the arterial emission factor ($ARF_{PM_{10}}$ & $ARF_{PM_{2.5}}$) before being multiplied by the VMTR by bicycle/pedestrian facilities. The arterial paved road PM₁₀ and PM_{2.5} emission factors for all roads ($PEF_{PM_{10}}$ and $PEF_{PM_{2.5}}$, or 0.35 and 0.0875 grams per mile, respectively) are added to $ARF_{PM_{10}}$ and $ARF_{PM_{2.5}}$. If a bike lane project includes shoulder paving, is located within 4 miles of a PM₁₀ monitor, the additional paved road PM₁₀ and PM_{2.5} emission reduction credit (0.27 and 0.0675 grams per mile, respectively) is added. If a bike lane project includes shoulder paving and is located within 4 miles of a PM₁₀ monitor, the

⁸ TTI also cross verified with FHWA CMAQ methodologies and Atlanta Regional Commission CMAQ strategies.

additional paved road PM₁₀ and PM_{2.5} emission reduction credit (0.66 and 0.165 grams per mile, respectively) is added.

Formulas

Below shows the formulas to calculate VTR and VMTR.

$$VTR = AADT \times (A + C)$$

where: **A** = the adjustment factor from Table 9;

C = the activity center credit from Table 10; and

AADT = the weekday ADT on the adjacent or nearest parallel arterial (maximum = 30,000 weekday ADT) multiplied by 0.93.

$$VMTR = VTR \times \text{trip length}$$

where: **trip length** = the length of a bicycle trip is assumed to be 4.64 miles, and the length of a pedestrian trip is assumed to be 0.50 miles. For a multi-use path, it is assumed that the average trip length is 2.57 miles.

Vehicle Emissions Reduced

Below shows the formula to calculate VER.

$$VER = \left[VMTR \right. \\ * \left(\frac{w_1 \times ARF_{CO}}{s_1} + \frac{w_2 \times ARF_{VOC}}{s_2} + \frac{w_3 \times ARF_{NOx}}{s_3} + \frac{w_4 \times (ARF_{PM10} + PEF_{PM10})}{s_4} \right. \\ \left. \left. + \frac{w_5 \times (ARF_{PM2.5} + PEF_{PM2.5})}{s_5} \right) \right. \\ + VTR \\ \left. \times \left(\frac{w_1 \times OFF_{CO}}{s_1} + \frac{w_2 \times OFF_{VOC}}{s_2} + \frac{w_3 \times OFF_{NOx}}{s_3} + \frac{w_4 \times OFF_{PM10}}{s_4} \right. \right. \\ \left. \left. + \frac{w_5 \times OFF_{PM2.5}}{s_5} \right) \right] * \frac{1}{1000} = \frac{kg}{day}$$

where: **OFF** = the off-network light-duty vehicle emission factor for each pollutant;

ARF = the arterial light-duty vehicle emission factor for each pollutant;

PEF_{PM10} = the paved road PM₁₀ emission factor for non-freeways (0.35 grams per mile) and for shoulders (0.27 grams per mile);

PEF_{PM2.5} = the paved road PM_{2.5} emission factor for non-freeways (0.0875 grams per mile) and for shoulders (0.675 grams per mile);

w1–w5 = priority weight factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively; and
s1–s5 = seasonal factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively.

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1+i)^{life} (i)}{(1+i)^{life} - 1}$$

where: **i** = discount rate of 3 percent; and

life = effectiveness period of 20 years for bicycle lanes on a road or shoulder; 30 years for a sidewalk, bicycle path, or pedestrian path; and 50 years for an overpass or underpass.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF * Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: **Cost** = the CMAQ funding requested for the project.

1.2 Bicycle and Pedestrian Facilities—Improved Facility

User-Defined Inputs and Constants

The methodology requires the set of project-specific, user-defined inputs presented in Table B5. The available defaults provided for these projects are shown in Table B6.

Table B5. Bicycle and Pedestrian—Improved Facility Project User-Defined Inputs

Input	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> Select the project location from the project location list.
Analysis Year		<ul style="list-style-type: none"> Select the analysis year from the list
Type of Improvement	-	<ul style="list-style-type: none"> Select from following improvements based on project objectives: "Widen the path", "Install buffer", or "Connect discontinuous paths".
Project Cost	dollars	<ul style="list-style-type: none"> Enter the estimated cost for the project.
AADT	vehicles/day	<ul style="list-style-type: none"> Enter the AADT on the nearest parallel arterial.
Number of activity centers within ¼ mile or ½ mile of the bicycle/pedestrian project	activity centers	<ul style="list-style-type: none"> Examples include a bank, church, hospital, health care facility, light-rail station, park-and-ride lot, office park, post office, public library, shopping area, grocery store, university or junior college.
Length of bicycle/pedestrian path	miles	<ul style="list-style-type: none"> Enter the length of the bicycle, pedestrian, or multi-use path. For a bridge/underpass, the path length of the bridge/ overpass will be twice if it is bi-directional as compared to if it is unidirectional.
Bicycle path or pedestrian path or multiuse path	-	<ul style="list-style-type: none"> Select the path usage from the path usage list.
Path Type	-	<ul style="list-style-type: none"> Select the path type from the path type list.
Percentage of additional vehicle trips reduced by improvement	percent	<ul style="list-style-type: none"> Enter an estimate of percentage of additional vehicle trips reduced by the improvement compared to the number of trips reduced by a new facility. For example, 10 percent can be interpreted as follows: an improvement would only reduce 10% of the trips compared to trips reduced by constructing a new facility.

Table B6. Bicycle and Pedestrian—Improved Facility Project Default Input Options and Constants*

Parameter	Value
Average speed of impacted vehicle (mph)	40
The adjustment factor	See Table 9
The activity center credit	See Table 9
The average trip length	Bicycle-4.64 Pedestrian-0.5 Multiuse-2.57

Parameter	Value
Effectiveness period/life of project (years)	50 years for overpass or underpass, 30 for sidewalk or path, 20 for the rest
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

The number of vehicles that can be replaced by bicycle or pedestrian (bicycle/pedestrian) trips are estimated based on the AADT on the adjacent or nearest parallel arterial to the bicycle/pedestrian facility; the weekday AADT is provided by the entity requesting funding for the project. The maximum allowable AADT is 30,000 vehicle trips per weekday. The vehicles reduced are calculated by multiplying the AADT by the sum of the adjustment factor (A) and the activity center credit (C).

The adjustment factor (A) in Table 9 is dependent upon the length of the bicycle/pedestrian project and the AADT on the road parallel to the bicycle/pedestrian project. Given the relative importance of bridges and underpasses that connect bicycle/pedestrian paths, the adjustment factor used for bridges and underpasses is based on the sum of the lengths of the two connected paths.

The usefulness of a bicycle/pedestrian facility is also dependent upon its location. Usage estimates for bicycle/pedestrian facilities take into consideration the number of activity centers near the proposed facility. The credit (C) for activity centers located along a bicycle/pedestrian facility is shown in Table 10.

Bicycle/pedestrian facilities are improved by adding a buffer to the bike lane or widening a bridge or changing the use of the path. These safety-related improvements presumably encourage the use of the facility. The difference in the VMT by improved bicycle/pedestrian facilities is estimated by multiplying the vehicles reduced by the average trip length. Consistent with the 2011 MAG CMAQ methodologies, a pedestrian trip length of 0.5 miles and an average bicycle trip length of 4.64 miles are assumed. For multi-use paths, it is assumed that half of the trips are bicycle and half are pedestrian. Therefore, an average trip length of 2.57 miles is used for multi-use paths.

The MOVES model was run to estimate CO, VOC, NO_x, PM₁₀ and PM_{2.5} emission factors for light-duty vehicles (ONF_{CO} , ONF_{VOC} , ONF_{NO_x} , $ONF_{PM_{10}}$, and $ONF_{PM_{2.5}}$), assuming a speed of 40 mph. The off-network emission factors in grams per vehicle per start (OFF_{CO} ,

OFF_{VOC} , OFF_{NOx} , $OFF_{PM_{10}}$, and $OFF_{PM_{2.5}}$) are multiplied by the number of VTR by bicycle/pedestrian trips. The arterial (Road Types 3 and 5) emission factors in grams per mile (ARF_{CO} , ARF_{VOC} , ARF_{NOx} , $ARF_{PM_{10}}$, $ARF_{PM_{2.5}}$) are multiplied by the VMTR by the bicycle/pedestrian trips.

For PM, the paved road emission factor for arterials ($PEF_{PM_{10}}$ & $PEF_{PM_{2.5}}$) is added to the arterial emission factor ($ARF_{PM_{10}}$ & $ARF_{PM_{2.5}}$) before being multiplied by the VMTR by bicycle/pedestrian facilities. The arterial paved road PM_{10} and $PM_{2.5}$ emission factors for all roads ($PEF_{PM_{10}}$ and $PEF_{PM_{2.5}}$, or 0.35 and 0.0875 grams per mile, respectively) is added to $ARF_{PM_{10}}$ and $ARF_{PM_{2.5}}$. If a bike lane project includes shoulder paving, is located within 4 miles of a PM_{10} monitor, the additional paved road PM_{10} and $PM_{2.5}$ emission reduction credit (0.27 and 0.0675 grams per mile, respectively) is added. If a bike lane project includes shoulder paving, is located within 4 miles of a PM_{10} monitor, the additional paved road PM_{10} and $PM_{2.5}$ emission reduction credit (0.66 and 0.165 grams per mile, respectively) is added.

The formulas below are used to calculate the emission reductions and cost effectiveness for improved bicycle and pedestrian facilities.

Formulas

Below shows the formulas to calculate VTR and VMTR.

$$VTR = AADT \times (A + C) \times p$$

where: **A** = the adjustment factor from Table 9;

C = the activity center credit from Table 10;

AADT = the weekday ADT on the adjacent or nearest parallel arterial (maximum = 30,000 weekday ADT) multiplied by 0.93; and

p = percentage of additional vehicle trips reduced by improvements in bicycle and pedestrian project facilities.

$$VMTR = VTR \times \text{trip length}$$

where: **trip length** = the length of a bicycle trip is assumed to be 4.64 miles, and the length of a pedestrian trip is assumed to be 0.50 miles. For a multiuse path, it is assumed that the average trip length is 2.57 miles.

Vehicle Emissions Reduced

Below shows the formula to calculate VER.

$$\begin{aligned}
 VER = & \left[VMTR \right. \\
 & * \left(\frac{w_1 \times ARF_{CO}}{s_1} + \frac{w_2 \times ARF_{VOC}}{s_2} + \frac{w_3 \times ARF_{NOx}}{s_3} + \frac{w_4 \times (ARF_{PM10} + PEF_{PM10})}{s_4} \right. \\
 & \left. \left. + \frac{w_5 \times (ARF_{PM2.5} + PEF_{PM2.5})}{s_5} \right) \right. \\
 & + VTR \\
 & \times \left(\frac{w_1 \times OFF_{CO}}{s_1} + \frac{w_2 \times OFF_{VOC}}{s_2} + \frac{w_3 \times OFF_{NOx}}{s_3} + \frac{w_4 \times OFF_{PM10}}{s_4} \right. \\
 & \left. \left. + \frac{w_5 \times OFF_{PM2.5}}{s_5} \right) \right] * \frac{1}{1000} = \frac{kg}{day}
 \end{aligned}$$

where: **OFF** = the off-network light-duty vehicle emission factor for each pollutant;

ARF = the arterial light-duty vehicle emission factor for each pollutant;

PEF_{PM10} = the paved road PM₁₀ emission factor for non-freeways (0.35 grams per mile) and for shoulders (0.27 grams per mile);

PEF_{PM2.5} = the paved road PM_{2.5} emission factor for non-freeways (0.0875 grams per mile) and for shoulders (0.675 grams per mile);

w1–w5 = priority weight factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively; and

s1–s5 = seasonal factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively.

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1 + i)^{life} (i)}{(1 + i)^{life} - 1}$$

where: **i** = discount rate of 3 percent; and

life = effectiveness period of 20 years for bicycle lanes on a road or shoulder; 30 years for a sidewalk, bicycle path, or pedestrian path; and 50 years for an overpass or underpass.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF * Cost * 1000}{Daily\ Emissions\ Reduction * 365} = \frac{dollars}{metric\ ton}$$

where: **Cost** = the CMAQ funding requested for the project.

2.0. CONGESTION AND TRAFFIC FLOW IMPROVEMENTS

Congestion and Traffic flow improvements include projects that accomplish the following:

- Adding Turning Lanes.
- Construct roundabouts.
- Traffic signal coordination

2.1 Intersection Improvements

User-Defined Inputs, Optional Defaults, and Constants

The methodology requires the set of project-specific, user-defined inputs, in a few cases with default input options, presented in Table B7 The available defaults provided for these projects are shown in Table B8.

Table B7. Additional Turning Lanes Project User-Defined Inputs

Input	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> • Select the location of project area from the area drop-down list.
Analysis year (project estimated time of completion)	-	<ul style="list-style-type: none"> • Enter the analysis year of the project.
Project Cost	dollars	<ul style="list-style-type: none"> • Enter the estimated cost for the project.
AADT both directions	vehicles/day	<ul style="list-style-type: none"> • Enter AADT for both streets that form the intersection. • For a standard four-legged intersection with northbound; southbound; eastbound; and westbound legs, enter the AADT for Northbound & Southbound and Eastbound & Westbound streets.
Estimated peak hourly traffic (both directions)	vehicles/hour	<ul style="list-style-type: none"> • Enter the estimated peak hour traffic of the project area. • If field data are not available, 10 percent of weekday ADT is a reasonable estimate.
Number of equivalent through lanes (both directions)	-	<ul style="list-style-type: none"> • Enter the number of equivalent through lanes for both cross street forming the intersection. • The left-turn lane and right-turn lane is equivalent to 0.5 through lanes.
Type of the street	-	<ul style="list-style-type: none"> • Select the street type from the street type list.
Truck percentage	percent	<ul style="list-style-type: none"> • Enter the truck percentage of the project area.

Input	Units	Input Guidance
Delay per vehicle during peak hours—before project	seconds/vehicle	<ul style="list-style-type: none"> Enter the estimated existing delay per vehicle during peak hours. If field data are not available, an appropriate delay value may be approximated from the table giving the intersection's existing LOS in HCM 2010 Exhibit 21-1.
Number of additional turning lanes	lanes	<ul style="list-style-type: none"> Enter the proposed additional turning lanes in the project.
Type of additional turning lanes	-	<ul style="list-style-type: none"> Select the type of additional turning lanes in the project.

Table B8. Additional Turning Lane Project Default Input Options and Constants*

Parameter	Value
Cycle length (seconds)	100
Effective green ratio	0.5
The equivalent number of through cars for a heavy-duty truck	2.00
The equivalent number of through cars for a protected right-turning vehicle	1.18
The equivalent number of through cars for a protected left-turning vehicle	1.05
Number of peak hours	6
Effectiveness period/life of project (years)	20
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

The methodology for calculating daily emission reductions is derived from the calculation of delay reduction at the intersection by the additional turning lane. The basic intersection layout with directions and vehicle movements is shown in Figure B1. The steps of the calculation consist of the following:

- Calculate the volume-to-capacity ratio of each lane group for the pre-project scenario and post-project scenario (northbound and southbound, or eastbound and westbound).
- Determine the highest volume-to-capacity ratio of any lane group at the intersection to calculate the intersection uniform delay for the pre-project scenario and post-project scenario.
- In each time period of the day (peak or off-peak), the delay reduction is the intersection uniform delay reduction multiplied by the number of vehicles in that period.

- The daily delay reduction is the sum of the peak delay reduction and the sum of off-peak delay reduction.
- The daily emission reduction is calculated by multiplying the daily delay reduction by the weighted idling emission rates.

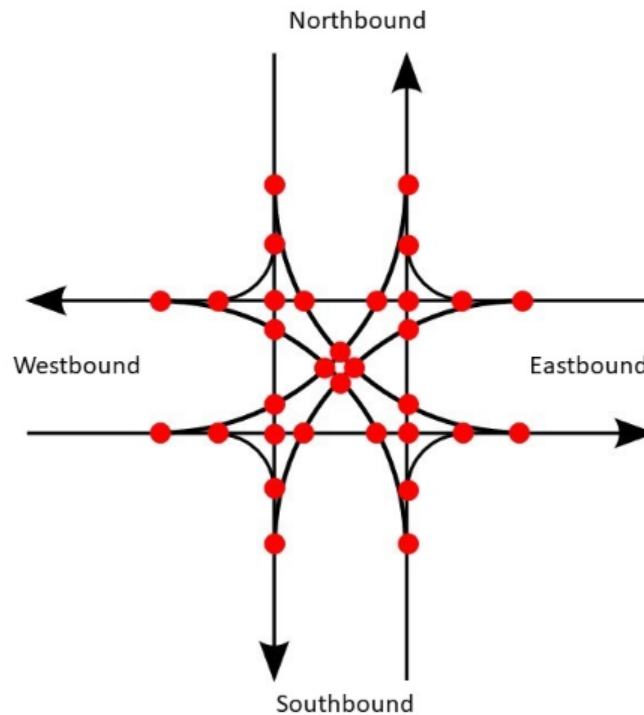


Figure B1. Intersection layout with directions and movements

Formulas

Below shows the formula to calculate d_1 .

$$d_1 = \frac{0.5C(1 - \frac{g}{C})^2}{1 - [\min(1, X) \frac{g}{C}]}$$

where: d_1 = uniform delay at a signalized intersection;

g/C = effective green ratio (the default is 0.5);

C = cycle length (the default value is 100 seconds);

$\min(1, X)$ = limit the volume-to-capacity ratio to maximum of 1.0; and

X = highest volume-to-capacity ratio of any lane group at the intersection:

$$X = \frac{v}{c} = \frac{v}{Nc_{lane}}$$

where: v = volume (vehicles/hour);

c = capacity;

N = number of through lane equivalents; and
 C_{lane} = capacity of the lane:

$$C_{lane} = C_0 f_{HV} f_{RT} f_{LT}$$

where: C_0 = base roadway capacity of through lane (passenger cars/lane/hour—see Table B9);

$$f_{HV} = \text{adjustment factor for heavy-duty vehicles} = \frac{100}{100 + P_{HV}(E_T - 1)},$$

where: P_{HV} = truck percentage and E_T = car equivalency for trucks = 2.0;

$$f_{RT} = \text{adjustment factor for protected right turns} = \frac{1}{E_R},$$

where: E_R = car equivalency for right-turn vehicle = 1.18; and

$$f_{LT} = \text{adjustment factor for protected left turns} = \frac{1}{E_L},$$

where: E_L = car equivalency for left-turn vehicle = 1.05.

Table B9. Lane Capacity Table

Road Type	Value
Principal Arterial Class I	1,225
Principal Arterial Class II	1,025
Minor Arterial Class I	925
Minor Arterial Class II	825
Minor Collector	525

Daily Delay Reduction (DR)

$$= \frac{(d_{pre-peak} - d_{post-peak}) \times v_{peak}}{3600} + \frac{(d_{pre-offpeak} - d_{post-offpeak}) \times v_{offpeak}}{3600}$$

where: $d_{pre-peak}$ = delay per vehicle during peak hours pre-project (the default value is 50 seconds/vehicle—LOS F);

$d_{post-peak}$ = delay per vehicle during peak hours post-project, by using the formula above to calculate;

$d_{pre-offpeak}$ = delay per vehicle during off-peak hours pre-project, by using the formula above to calculate;

$d_{post-offpeak}$ = delay per vehicle during off-peak hours post-project, by using the formula above to calculate;

P_{HV} = truck percentage = 2.0;

E_T = car equivalency for trucks = 2.0;

f_{RT} = adjustment factor for protected right turns = $\frac{1}{E_R}$;

E_R = car equivalency for right-turn vehicle = 1.18;

f_{LT} = adjustment factor for protected left turns = $\frac{1}{E_L}$; and

E_L = car equivalency for left-turn vehicle = 1.05.

Vehicle Emissions Reduced

Below shows the formula to calculate VER.

$$VER = DR_{LDV} \times \left(\frac{w_1 IEF_{CO-LDV}}{s_1} + \frac{w_2 IEF_{NOx-LDV}}{s_2} + \frac{w_3 IEF_{VOC-LDV}}{s_3} + \frac{w_4 IEF_{PM_{10-LDV}}}{s_4} + \frac{w_5 IEF_{PM_{2.5-LDV}}}{s_5} \right) + DR_{HDV} \times \left(\frac{w_1 IEF_{CO-HDV}}{s_1} + \frac{w_2 IEF_{NOx-HDV}}{s_2} + \frac{w_3 IEF_{VOC-HDV}}{s_3} + \frac{w_4 IEF_{PM_{10-HDV}}}{s_4} + \frac{w_5 IEF_{PM_{2.5-HDV}}}{s_5} \right) = \frac{kg}{day}$$

where: **IEF** = the idling emission factor of all the pollutants;

w1–w5 = priority weight factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively; and

s1–s5 = seasonal factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively.

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1 + i)^{life(i)}}{(1 + i)^{life} - 1}$$

where: **i** = discount rate of 3 percent; and

life = effectiveness period of 20 years.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF \times cost \times 1000}{VER \times 365} = \frac{dollars}{metric\ ton}$$

where: **Cost** = the funding requested for the project.

2.2. Traffic Signal Coordination Projects

User-Defined Inputs, Optional Defaults, and Constants

The methodology requires the set of project-specific, user-defined inputs, in a few cases with default input options, presented in Table B10. The available defaults provided for these projects are shown in Table B11.

Table B10. Traffic Signal Coordination Project User-Defined Inputs

Input	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> Select the location of the project area from area drop-down list.
Analysis year (project estimated time of completion)	-	<ul style="list-style-type: none"> Enter the analysis year of the project.
Project Cost	dollars	<ul style="list-style-type: none"> Enter the estimated cost for the project.
AADT	vehicles/day	<ul style="list-style-type: none"> Enter the AADT of the project area.
Length of project	miles	<ul style="list-style-type: none"> Enter the length of the project.
Estimated hourly traffic	vehicles/hour	<ul style="list-style-type: none"> Enter the estimated hourly traffic for the peak and off-peak period. If field data are not available, 10 percent of weekday ADT is a reasonable estimate.
Pre-project speed	mph	<ul style="list-style-type: none"> Enter the pre-project speed along the corridor.
The category into which the proposed project is classified	-	<ul style="list-style-type: none"> Select the classification of the project from the classification list. Refer to Table 18.

Table B11. Traffic Signal Coordination Project Default Input Options and Constants*

Parameter	Value
Number of peak hours	6
Effectiveness period/life of project (years)	5
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

The signal coordination will reduce the delay of the vehicles and improve the progression of the vehicles moving along the corridor where the signals are well coordinated based on traffic flow information. The improved speed will lead to emission reductions in CO, VOC, NO_x, PM₁₀ and PM_{2.5}.

MOVES was run to estimate the running emission factors for CO, VOC, NO_x, PM₁₀ and PM_{2.5} for all vehicle classes in the year of pre-project implementation (BEF_{CO}, BEF_{VOC},

BEF_{NOx}, BEF_{PM10}, and BEF_{PM2.5}) and of the post-project scenario (AEF_{CO}, AEF_{VOC}, AEF_{NOx}, AEF_{PM10}, and AEF_{PM2.5}). The information in Table 18, obtained from CARB,⁷ is used to quantify the speed change from pre-project to post-project in each category. The length of the project, the weekday ADT, the pre-project speed, and the category in Table B12 that best represents the proposed project is provided by the agency requesting CMAQ funding and used to calculate the emission benefits of traffic signal coordination projects.

Table B12. Traffic Signal Coordination: Post-Project Speeds

Category	Before Condition	After Condition	Increase in Speed
One	Non-interconnected, pre-timed signals with old timing plan	Advanced computer-based control. Coordinated time-of-day operations. Adaptive Signal Control.	25%
Two	Interconnected, pre-timed signals with old timing plan	Advanced computer-based control. Coordinated time-of-day operations. Adaptive Signal Control.	17.5%
Three	Non-interconnected signals with traffic-actuated controllers	Advanced computer-based control. Coordinated time-of-day operations. Adaptive Signal Control.	16%
Four	Interconnected, pre-timed signals with actively managed timing. For example, the timing is adjusted every month but the timing plan is still pre-timed, not traffic actuated.	Advanced computer-based control. Coordinated time-of-day operations. Adaptive Signal Control.	8%
Five	Interconnected, pre-timed signals with various forms of master control, such as traffic-actuated control or manual control and pre-set various qualities of timing plans.	Optimization of signal timing plans. No change in hardware.	12%
Six	Non-interconnected, pre-timed signals with old timing plan	Optimization of signal timing plan.	7.5%

Formulas

Vehicle Emissions Reduced

Below shows the formula to calculate VER.

$$\begin{aligned}
VER = & \text{miles} \times v_{\text{peak}} \times n_{\text{peak}} \times 0.93 \\
& \times \left(\left(\frac{w_1 BEF_{CO-\text{peak}}}{s_1} + \frac{w_2 BEF_{NOx-\text{peak}}}{s_2} + \frac{w_3 BEF_{VOC-\text{peak}}}{s_3} + \frac{w_4 BEF_{PM10-\text{peak}}}{s_4} \right. \right. \\
& \left. \left. + \frac{w_5 BEF_{PM2.5-\text{peak}}}{s_5} \right) \right. \\
& \left. - \left(\frac{w_1 AEF_{CO-\text{peak}}}{s_1} + \frac{w_2 AEF_{NOx-\text{peak}}}{s_2} + \frac{w_3 AEF_{VOC-\text{peak}}}{s_3} + \frac{w_4 AEF_{PM10-\text{peak}}}{s_4} \right. \right. \\
& \left. \left. + \frac{w_5 AEF_{PM2.5-\text{peak}}}{s_5} \right) \right) \\
& + \text{miles} \times v_{\text{offpeak}} \times n_{\text{offpeak}} \times 0.93 \\
& \times \left(\left(\frac{w_1 BEF_{CO-\text{offpeak}}}{s_1} + \frac{w_2 BEF_{NOx-\text{offpeak}}}{s_2} + \frac{w_3 BEF_{VOC-\text{offpeak}}}{s_3} \right. \right. \\
& \left. \left. + \frac{w_4 BEF_{PM10-\text{offpeak}}}{s_4} + \frac{w_5 BEF_{PM2.5-\text{offpeak}}}{s_5} \right) \right. \\
& \left. - \left(\frac{w_1 AEF_{CO-\text{offpeak}}}{s_1} + \frac{w_2 AEF_{NOx-\text{offpeak}}}{s_2} + \frac{w_3 AEF_{VOC-\text{offpeak}}}{s_3} \right. \right. \\
& \left. \left. + \frac{w_4 AEF_{PM10-\text{offpeak}}}{s_4} + \frac{w_5 AEF_{PM2.5-\text{offpeak}}}{s_5} \right) \right) \times \frac{1}{1000} = \frac{kg}{day}
\end{aligned}$$

where:

miles = the length of the project;

ADT_{weekday} = weekday ADT = $v_{\text{peak}} \times n_{\text{peak}} + v_{\text{offpeak}} \times n_{\text{offpeak}}$;

0.93 = the factor for converting weekday ADT to annual average daily traffic on arterials;

BEF = the emission factor for all vehicle classes at the pre-project speed;

AEF = the emission factor at the post-project speed;

w1–w5 = priority weight factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively; and

s1–s5 = seasonal factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively.

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1+i)^{\text{life}}(i)}{(1+i)^{\text{life}} - 1}$$

where: **i** = discount rate of 3 percent; and

life = effectiveness period of 5 years.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$\text{Cost Effectiveness} = \frac{CRF \times \text{Cost} \times 1000}{VER \times 365} = \frac{\text{dollars}}{\text{metric ton}}$$

where: **Cost** = the CMAQ funding requested for the project.

2.3 Roundabouts

User-Defined Inputs, Optional Defaults, and Constants

The methodology requires the set of project-specific, user-defined inputs, in a few cases with default input options, presented in Table B13. The available defaults provided for these projects are shown in Table B14.

Table B13. Roundabouts Project User-Defined Inputs

Input	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> Select the location of project area from the area drop-down list.
Analysis year (project estimated time of completion)	-	<ul style="list-style-type: none"> Enter the analysis year of the project.
CMAQ cost for the project	dollars	<ul style="list-style-type: none"> Enter the estimated CMAQ cost for the project.
AADT	vehicles/day	<ul style="list-style-type: none"> Enter the AADT of the project area for eastbound, westbound, northbound, and southbound traffic.
Estimated peak hourly traffic	vehicles/hour	<ul style="list-style-type: none"> Enter the estimated peak hour traffic of the project area for each direction of travel. If field data are not available, 10 percent of weekday AADT is a reasonable estimate.
Number of equivalent entry lanes	-	<ul style="list-style-type: none"> Enter the number of equivalent through lanes of the project area.
Truck percentage	percent	<ul style="list-style-type: none"> Enter the truck percentage of the project area.
Delay per vehicle during peak hours—before	seconds/vehicle	<ul style="list-style-type: none"> Enter the estimated existing delay per vehicle during peak hours. If field data are not available, an appropriate delay value may be approximated from the table giving the intersection's existing LOS in HCM 2010 Exhibit 21-1.
Delay per vehicle during off-peak hours—before	seconds/vehicle	<ul style="list-style-type: none"> Enter the estimated existing delay per vehicle during off-peak hours. If field data are not available, an appropriate delay value may be approximated from the table giving the intersection's existing LOS in HCM 2010 Exhibit 21-1.
Existing intersection left-turn percentage	-	<ul style="list-style-type: none"> Enter the intersection left-turn percentage. If field data are not available, use historical data to estimate the left-turn percentage.

Input	Units	Input Guidance
Existing intersection right-turn percentage	-	<ul style="list-style-type: none"> Enter the intersection right-turn percentage. If field data are not available, use historical data to estimate the right-turn percentage.
Number of circulating roundabout lanes	lanes	<ul style="list-style-type: none"> Enter the number of circulating lanes in the roundabout.

Table B14. Roundabouts Project Default Input Options and Constants*

Parameter	Value
The equivalent number of through cars for a heavy-duty truck	2.00
Weekday ADT to AADT conversion factor	0.93 for arterials
Number of peak hours (hours/day)	6
Effectiveness period/life of project (years)	20
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

The daily emission reductions attained by construction roundabouts to replace traditional four-way intersections is derived from the calculation of the delay reduction at the intersection before and after the construction of the roundabout. The basic intersection layout with directions and vehicle movements is shown in Figure B2. Roundabout intersection layout with directions and the capacity of each approach is heavily influenced by several conflicting flows coming into the roundabout for the subject lane. Using Figure B2 as an example, the conflicting flows of each approach are described below:

- Eastbound approach: southbound through and left-turn traffic and westbound left-turn traffic.
- Westbound approach: northbound through and left-turn traffic and eastbound left-turn traffic.
- Northbound approach: eastbound through and left-turn traffic and southbound left-turn traffic.
- Southbound approach: westbound through and left-turn traffic and northbound left-turn traffic.

The steps of the calculation consist of the following:

- Calculate the conflicting flow within the roundabout that will influence the capacity of each roundabout approach.
- Calculate the capacity of each approach into a roundabout.
- Calculate the volume-to-capacity ratio of each lane group for pre-project and post-project scenarios (northbound, southbound, eastbound, and westbound).
- Determine the highest volume-to-capacity ratio of any lane group at the intersection to calculate the intersection uniform delay for pre-project and post-project scenarios.
- In each time period of the day (peak or off-peak), the delay reduction will be the intersection uniform delay reduction multiplied by the number of vehicles in that period.
- The daily delay reduction is the sum of the peak delay reduction and the sum of the off-peak delay reduction.
- The daily emission reduction will be calculated by multiplying the daily delay reduction by the weighted idling emission rates.

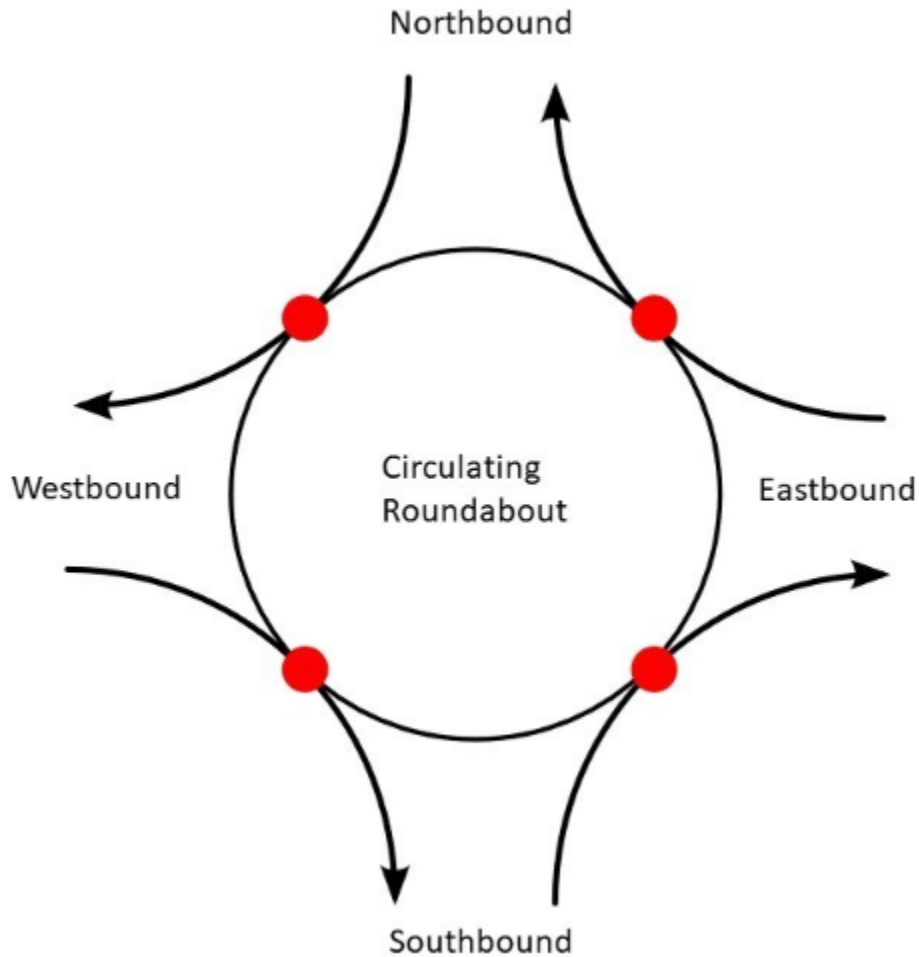


Figure B2. Roundabout intersection layout with directions and movements

Formulas

Average Control Delay

Below shows the formula for d .

$$d = \frac{3600}{c} + 900T \left[x - 1 + \sqrt{(x - 1)^2 + \frac{3600}{c} x} \right] + 5 \times \min(1, x)$$

where: d = average control delay (seconds/vehicle);

T = time period (hours);

c = capacity of the subject line (vehicles/hour);

$\min(1, X)$ = limit the volume-to-capacity ratio to maximum of 1.0; and

X = highest volume-to-capacity ratio of any lane group at the intersection;

$$X_i = \frac{v_{pce,i}}{c_{pce,i}}$$

where: \mathbf{v} = volume (vehicles/hour); and
 \mathbf{c} = capacity.

For each approach i , the volume is calculated as follows:

$$v_{i,pce} = \frac{v_i}{f_{HV}}$$

where: \mathbf{v}_i = the volume of each approach; and

$$\mathbf{f}_{HV} = \text{adjustment factor for heavy-duty vehicles} = \frac{100}{100 + P_{HV}(E_T - 1)}.$$

With different numbers of approach lanes and circulating lanes, the capacity is calculated as follows:

$$c_{pce} = 1130e^{(-1.0 \times 10^{-3})v_{c,pce}}, N_C = 1$$

$$c_{pce} = \begin{cases} 1130e^{(-0.7 \times 10^{-3})v_{c,pce}}, N = 1 \\ 1130e^{(-0.7 \times 10^{-3})v_{c,pce}} + 1130e^{(-0.75 \times 10^{-3})v_{c,pce}}, N = 2 \end{cases} N_C = 2$$

where: \mathbf{N} = number of approach lanes;

\mathbf{N}_C = number of circulating lanes; and

$\mathbf{v}_{c,pce}$ = conflicting flow of each approach:

$$v_{c,pce} = (1 - P_{RT,n-1})v_{pce,n-1} + (P_{LT,n-2})v_{pce,n-2}$$

where: \mathbf{N} = number of approach lanes;

$\mathbf{P}_{RT,n-1}$ = percent of right-turning vehicles from the next approach clockwise;

$\mathbf{v}_{pce,n-1}$ = volume from the next approach clockwise;

$\mathbf{P}_{LT,n-2}$ = percent of left-turning vehicles from the approach opposite direction; and

$\mathbf{v}_{pce,n-2}$ = volume from the approach opposite direction.

For each approach and intersection, delay reductions can be calculated as follows:

$$\begin{aligned} & \text{Daily Delay Reduction (DR)} \\ &= \frac{(d_{pre-peak} - d_{post-peak}) \times v_{peak}}{3600} \\ &+ \frac{(d_{pre-offpeak} - d_{post-offpeak}) \times v_{offpeak}}{3600} \end{aligned}$$

where: $d_{pre-peak}$ = delay per vehicle during peak hours pre-project (the default value is 50 second/vehicle—LOS F);
 $d_{post-peak}$ = delay per vehicle during peak hours post-project, by using the formula above to calculate;
 $d_{pre-offpeak}$ = delay per vehicle during off-peak hours pre-project, by using the formula above to calculate; and
 $d_{post-offpeak}$ = delay per vehicle during off-peak hours post-project, by using the formula above to calculate.

Vehicle Emissions Reduced

Below shows the formula to calculate VER.

$$VER = DR_{LDV} \times \left(\frac{w_1 IEF_{CO-LDV}}{s_1} + \frac{w_2 IEF_{NOx-LDV}}{s_2} + \frac{w_3 IEF_{VOC-LDV}}{s_3} + \frac{w_4 IEF_{PM_{10-LDV}}}{s_4} + \frac{w_5 IEF_{PM_{2.5-LDV}}}{s_5} \right) + DR_{HDV} \times \left(\frac{w_1 IEF_{CO-HDV}}{s_1} + \frac{w_2 IEF_{NOx-HDV}}{s_2} + \frac{w_3 IEF_{VOC-HDV}}{s_3} + \frac{w_4 IEF_{PM_{10-HDV}}}{s_4} + \frac{w_5 IEF_{PM_{2.5-HDV}}}{s_5} \right) = \frac{kg}{day}$$

where: IEF = the idling emission factor;
 $w1-w5$ = priority weight factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively; and
 $s1-s5$ = seasonal factors for CO, VOC, NO_x, PM₁₀, and PM_{2.5}, respectively.

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1+i)^{life}(i)}{(1+i)^{life} - 1}$$

where: i = discount rate of 3 percent; and
 $life$ = effectiveness period of 20 years.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF \times cost \times 1000}{Daily\ Emission\ Reduction \times 365} = \frac{dollars}{metric\ ton}$$

where: **Cost** = the CMAQ funding requested for the project.

3.0 IDLING REDUCTION PROGRAMS

This scenario quantifies the emission reduction related to idling activities within idling reduction zones designated for school buses or heavy-duty trucks. The emission reductions are estimated based on reduced idling hours per vehicle, number of vehicles within the zone, and potential emission increment due to additional engine start.

3.1. Truck Idling Reduction Zone

User-Defined Inputs and Constants

The methodology requires the set of project-specific, user-defined inputs presented in Table B15. The available defaults and constants provided for these projects are shown in Table B16.

Table B15. Truck Idling Reduction Zone User-Defined Inputs

Inputs	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> Select the location of project area from the area drop-down list.
Project Cost	dollars	<ul style="list-style-type: none"> Enter the estimated cost for the project.
Number of Trucks	vehicles	<ul style="list-style-type: none"> Enter the number of trucks passing through designated zone per day
Percent of complying trucks		<ul style="list-style-type: none"> Percentage of trucks comply with idling reduction rules
Average idling hours per truck BEFORE building the idling reduction zone	Hour/vehicle	<ul style="list-style-type: none"> Enter the average idling hours before the project
Average idling hours per truck AFTER building the idling reduction zone	Hours/Vehicle	<ul style="list-style-type: none"> Enter the average idling hours after the project
Additional engine start per vehicle AFTER building the idling reduction zone	Starts/vehicle	<ul style="list-style-type: none"> Enter the additional starts after the project

Table B16. Truck Idling Reduction Zone Project Default Input Options and Constants*

Parameter	Values
Effectiveness period/life of the project (years)	5
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

Emissions are reduced because trucks will turn off their engines and receive compartment cooling/heating and other services (cable TV, high-speed internet) from the electric stalls during rest stops. Another example of an anti-idling program is the installation of APUs on a fleet of diesel trucks that operate primarily within a nonattainment or maintenance area. APUs are a mobile idle reduction technology that provide air conditioning, heat, and power for sleeper cab appliances, as well as battery charging and start assists for the main engine. They can be diesel or battery-powered or a combination of both.

To quantify the benefit of an anti-idling project, MOVES was run to estimate extended idling emission factors and APU idling emission factors for NO_x, PM₁₀ and PM_{2.5} for heavy-duty diesel vehicles in the year of project implementation. The idling emission rates for electric heavy-duty vehicles are zero for all the pollutants. The emission rate differences are calculated by subtracting the post-project APU or electric emission rates from the pre-project extended idling emission rates. The rate differences in grams per vehicle per hour are multiplied by the estimated daily reduction in idling hours to calculate the daily emission reductions. The resultant emissions represent the reduction benefit of a truck stop electrification or an APU project. The emission reduction is combined with capital recovery factor and cost to calculate the cost effectiveness of the project.

Formulas

Vehicle Emissions Reduced

Below shows the formula to calculate daily emission reduction

Daily Emission Reduction = Number of complied trucks * idling hour reduction per truck * idling emission rate - Number of complied trucks * additional engine start per truck * start emission rate

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1 + i)^{life}(i)}{(1 + i)^{life} - 1}$$

where: ***i*** = discount rate of 3 percent; and
life = effectiveness period of 5 years.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF \times Cost \times 1000}{Daily\ Emissions\ Reduction \times 365} = \frac{dollars}{metric\ ton}$$

where: **Cost** = the funding requested for the project.

3.2. School Zone Idling Reduction

User-Defined Inputs and Constants

The methodology requires the set of project-specific, user-defined inputs presented in Table B17. The available defaults and constants provided for these projects are shown in Table B18.

Table B17. School Zone Idling reduction User-Defined Inputs

Inputs	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> Select the location of project area from the area drop-down list.
Project Cost	dollars	<ul style="list-style-type: none"> Enter the estimated cost for the project.
Number of Buses	vehicles	<ul style="list-style-type: none"> Enter the number of trucks passing through designated zone per day
Percent of complying Buses		<ul style="list-style-type: none"> Percentage of trucks comply with idling reduction rules
Average idling hours per bus BEFORE building the idling reduction zone	Hour/vehicle	<ul style="list-style-type: none"> Enter the average idling hours before the project
Average idling hours per bus AFTER building the idling reduction zone	Hours/Vehicle	<ul style="list-style-type: none"> Enter the average idling hours after the project
Additional engine start per vehicle AFTER building the idling reduction zone	Starts/vehicle	<ul style="list-style-type: none"> Enter the additional starts after the project

Table B18. School Zone Idling reduction Project Default Input Options and Constants*

Parameter	Values
Effectiveness period/life of the project (years)	5
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

Emissions are reduced because bus will turn off their engines . To quantify the benefit of an anti-idling project, MOVES was run to estimate extended idling emission factors and APU idling emission factors for NO_x, PM₁₀ and PM_{2.5} for heavy-duty diesel vehicles in

the year of project implementation. The idling emission rates for electric heavy-duty vehicles are zero for all the pollutants. The emission rate differences are calculated by subtracting the post-project APU or electric emission rates from the pre-project extended idling emission rates. The rate differences in grams per vehicle per hour are multiplied by the estimated daily reduction in idling hours to calculate the daily emission reductions. The emission reduction is combined with capital recovery factor and cost to calculate the cost effectiveness of the project.

Formulas

Vehicle Emissions Reduced

Below shows the formula to calculate daily emission reduced

Daily Emission Reduction = Number of complied buses * idling hour reduction per bus * idling emission rate - Number of complied buses * additional engine start per bus * start emission rate

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1 + i)^{life}(i)}{(1 + i)^{life} - 1}$$

where: ***i*** = discount rate of 3 percent; and

life = effectiveness period of 5 years.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF \times Cost \times 1000}{Daily\ Emissions\ Reduction \times 365} = \frac{dollars}{metric\ ton}$$

where: ***Cost*** = the funding requested for the project.

4.0 VEHICLE REPLACEMENT PROGRAMS

This scenario assesses the emission reduction benefits from replacing high-emitter vehicles with clean, new vehicles. The vehicle types considered in this analysis include heavy duty trucks, light duty vehicles, school buses and transit buses. It can also be used for assessing retrofits or engine repowering by entering the applicable emissions reductions expected for various pollutants. The emission calculation is based on user input data on the number of vehicles to be replaced, daily operations per vehicle (VMT and speed), and vehicle information before and after replacement (model year, vehicle type, and fuel type). Users are also required to enter the percentage reduction in emissions expected for each pollutant based on the emissions characteristics.

4.1. Vehicle Replacement

User-Defined Inputs and Constants

The methodology requires the set of project-specific, user-defined inputs presented in Table B19. The available defaults and constants provided for these projects are shown in Table B20.

Table B19. Vehicle Replacement project User-Defined Inputs

Inputs	Units	Input Guidance
Project location	-	<ul style="list-style-type: none"> Select the location of project area from the area drop-down list.
Project Cost	dollars	<ul style="list-style-type: none"> Enter the estimated cost for the project.
Vehicle type (old vehicle)		<ul style="list-style-type: none"> Enter the vehicle type being replaced from the list
Fuel Type (old vehicle)		<ul style="list-style-type: none"> Enter the fuel type of the vehicle being replaced from the list
Model Year (old vehicle)	year	<ul style="list-style-type: none"> Enter the model year of the vehicle being replaced
Vehicle type (new vehicle)		<ul style="list-style-type: none"> Enter the vehicle type of replacing vehicle from the list
Fuel Type (new vehicle)		<ul style="list-style-type: none"> Enter the fuel type of replacing vehicle from the list
Model Year (new vehicle)	year	<ul style="list-style-type: none"> Enter the model year of replacing vehicle
Number of vehicles		<ul style="list-style-type: none"> Enter the number of vehicles being replaced
Mileage	Miles/day/vehicle	<ul style="list-style-type: none"> Enter the average daily mileage of the vehicles

Table B20. Vehicle Replacement project Default Input Options and Constants*

Parameter	Values
Average Vehicle Speed	
Effectiveness period/life of the project (years)	5
Year to day conversion (days/year)	365
Discount rate (percent)	3

*Default inputs can be replaced with project-specific inputs when available to improve cost effectiveness estimation accuracy.

Methodology

This method is designed to evaluate the benefits of clean vehicle program, which is to reduce emissions by replacing old vehicles with newer, cleaner vehicles, or providing complete engine replacement or retrofits that result in lower emissions. The method

estimates daily activity change if there is difference in number of vehicles and the difference in the average daily distance traveled between old and new vehicles.

Formulas

Vehicle Emissions Reduced

Below shows the formula to calculate daily emission reduction

Daily emission reduction = Number of replaced vehicles * daily VMT * (old vehicle running emission rate - new vehicle running emission rate) + Number of replaced vehicles * daily engine start * (old vehicle start emission rate - new vehicle start emission rate)

Capital Recovery Factor

Below shows the formula to calculate CRF.

$$CRF = \frac{(1 + i)^{life}(i)}{(1 + i)^{life} - 1}$$

where: ***i*** = discount rate of 3 percent; and

life = effectiveness period of 5 years.

Cost Effectiveness

Below shows the formula to calculate cost effectiveness.

$$Cost\ Effectiveness = \frac{CRF \times Cost \times 1000}{Daily\ Emissions\ Reduction \times 365} = \frac{dollars}{metric\ ton}$$

where: **Cost** = the funding requested for the project.