



# Creating Look-Up Tables to Streamline the Determination of Emission Reductions for CMAQ Projects

## Final Report

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Prepared for

**AASHTO Committee on Environment and Sustainability**

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## Disclaimer

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## Summary

To receive CMAQ funding, project sponsors are required to show how their projects will reduce emissions of at least one of five target pollutants (CO, VOC, PM<sub>10</sub>, PM<sub>2.5</sub>, and NO<sub>x</sub>). The objective of the NCHRP 25-25 Task 108 project was to develop a user-friendly spreadsheet tool for CMAQ project sponsors to reduce the time and cost needed to determine emissions reductions.

The project resulted in three main products: a spreadsheet tool containing all Project Type Tools compiled into a single Excel file, a user guide, and a package of all MOVES input and output databases. The NCHRP “Simplified Toolkit” covers 16 different project types, including new bus service, street sweeping, signal synchronization, and bicycle-pedestrian improvement projects, and models project evaluation years from 2020 to 2040.

As part of tool development, the research team developed simplified approaches to determining the changes in total emissions from CMAQ projects and programs. The tools calculate the change in emissions directly for users based on activity assumptions for the type of project, user inputs, and a database of emission rates incorporated in the tool. Recognizing that some activity inputs may be difficult for users to determine for specific projects, a reference table with default input assumptions was also developed. The table includes recommended default, low, and high input values for all Project Type tools, including daily VMT, signal delay, and average hourly traffic flow. The recommended default inputs are based on national averages drawn from various sources. The tools are pre-populated with average default values to the extent possible.

The Simplified Toolkit builds on work conducted for FHWA’s CMAQ Emissions Calculator Toolkit (“FHWA Toolkit”). The Simplified Toolkit uses streamlined methodology and inputs compared with the FHWA Toolkit, to provide project sponsors with a more efficient option to calculate emissions reductions. Comparisons show that the Simplified Toolkit gives results, which are in generally good agreement with the FHWA Toolkit. Observed differences are primarily attributed to the simplified methodology and some differences in underlying emissions and activity data between the two sets of tools.

The tools developed in this study may be applied by state departments of transportation, metropolitan planning agencies, and other project sponsors to estimate emission reductions for CMAQ-funded projects in accordance with federal requirements and in keeping with the objective for the study. However, this research is being conducted for NCHRP and therefore the deliverables are by definition not FHWA-products or necessarily FHWA-endorsed products.

## Introduction

The Congestion Mitigation and Air Quality Improvement (CMAQ) program was created by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and is closely linked to the 1990 Clean Air Act Amendments that formalized the linkage between transportation planning and air quality. The original program funded projects to improve air quality in nonattainment areas, and over time, the program expanded to also include maintenance areas and states without nonattainment or maintenance areas. The CMAQ program has been reauthorized by each subsequent transportation funding bill, including the Fixing America's Surface Transportation (FAST) Act. The purpose of the CMAQ program is to fund transportation projects or programs that will contribute to air quality improvements. Originally focused on ozone precursors (VOCs and NO<sub>x</sub>) and carbon monoxide, the program has evolved along with air quality planning priorities to include fine particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>).

To receive CMAQ funding, project sponsors (state DOTs and MPOs) are required to document the emissions reductions associated with their projects. Project sponsors may lack the time, expertise, or resources necessary to conduct robust emissions modeling for relatively small projects. At the same time, accurate emission reduction estimates have become increasingly important due to changes to the CMAQ program that put increased emphasis on performance measurement, cost effectiveness of the estimated emissions reductions, and efficiency in the project selection process. The efficiency of the CMAQ program has been extensively studied through congressionally mandated reviews addressing program effectiveness and project cost-efficiency.

Recognizing the need for easy-to-use and defensible emissions estimating tools for project sponsors, FHWA has developed a CMAQ Emissions Calculator Toolkit. The FHWA Toolkit provides a series of Excel-based calculators that allow a user to estimate emissions reductions associated with traffic flow improvements (intersection improvements, traffic signal synchronization, roundabouts), advanced diesel truck engine technologies (e.g., on-road diesel retrofits), and alternative vehicles/fuels. Additional toolkit modules recently published include transit bus replacements and engine retrofit projects, transit route expansion projects, bike and pedestrian projects, and diesel idle reduction projects. Modules for dust mitigation and managed lanes projects are currently in development.

The FHWA Toolkit requires substantial user input data, which in some cases is time consuming and expensive to develop. NCHRP 25-25 Task 108 is intended to develop a user-friendly spreadsheet tool with minimized and simplified inputs. The Task 108 Simplified Toolkit is independent of the FHWA Toolkit, but build on the work conducted for FHWA to provide project sponsors an additional option in calculating emissions reductions in an efficient manner.

NCHRP 25-25 Task 108 streamlines the process of determining emissions reductions for CMAQ projects by providing default input data for projects covered by the FHWA Toolkit. By providing default inputs for a range of “typical” projects (e.g., average daily VMT for combination trucks), users can quickly estimate emissions savings from different project options. This streamlined process will support more efficient applications for CMAQ funding and aid project sponsors in prioritizing projects based on emissions savings.

In comparison to the FHWA Toolkit, the NCHRP Simplified Toolkit tools are compiled into a single spreadsheet with one tab per project type. The Simplified Toolkit models project evaluation years out to 2040, using interpolated emission rates in 5-year increments between 2020 and 2040 (see Tool Development Process below for detail of interpolation method). The FHWA Toolkit has more refined emission rates for a limited number of future years. Both of these design approaches (single spreadsheet and interpolation) allowed for reduced development time and also reduce computational time to estimate emissions benefits.

## Report Overview

The following report sections provide a brief literature review of CMAQ research conducted to date, describe how project type categories were developed for the Simplified Toolkit, provide an overview of tool development and methodology, and present the results of comparisons with the FHWA Toolkit. A package of all the backup modeling files will also be made available on the NCHRP 25-25 website. Refer to the User Guide for default inputs for each Project Type tool. Default values are also pre-filled in each tool in the spreadsheet.

A total of 15 tools were developed to cover 16 project types as discussed in the Project Type Prioritization section, below. Two tools (Carpooling and Vanpooling) were developed for the Ridesharing Project Type and the Bike Lanes, Pedestrian Path, and Bike Sharing Project Types were combined into a single tool, since the methodology for calculating associated emissions reductions is equivalent.

The Intersection Improvements, Traffic Synchronization, Roundabouts, and Managed Lanes Project Type Tools were developed concurrently. Unlike the other project types associated with Task 108, these project types required project-level MOVES runs which were shared across those project types. The project-level inputs are described further in the Tool Development section.

### List of Project Type Tools:

1. Bus Replacement
2. New Transit Buses
3. New Bus Services
4. Diesel Engine Retrofits
5. Diesel Idle Reduction
6. Alternative to Diesel Engines and Engine Replacement
7. Ridesharing - Carpooling
8. Ridesharing - Vanpooling
9. Pedestrian Paths, Bike Lanes, Bike Sharing
10. Street Sweeping
11. Street Paving
12. Signal Synchronization
13. Intersection Improvements
14. Roundabouts
15. High-Occupancy Vehicles / Managed Lanes

## Literature Review

In addition to the CMAQ Emission Calculator Toolkit, FHWA has funded other research that supports the CMAQ program. In 2015, FHWA published the “Cost-Effectiveness Tables Development and Methodology,” which provides information on the development of estimates of cost effectiveness for a range of representative project types previously funded under the CMAQ program. FHWA developed cost-effectiveness tables because SAFETEA-LU directed states and MPOs to give priority to cost-effective transportation projects (including diesel retrofits and congestion mitigation efforts) that also produced an air quality benefit. MAP-21 also called for the development of cost-effectiveness tables for a range of CMAQ-eligible project types. The cost-effectiveness tables are intended to assist states, MPOs and other project sponsors as they make the most efficient use of their CMAQ dollars in reducing on-road vehicle emissions and traffic congestion.

In 2014, FHWA published the CMAQ case studies, which focused on the extent of the efforts being conducted by state DOTs and MPOs to address the MAP-21 PM 2.5 provisions. FHWA contracted the Volpe Center to conduct a survey of nine DOTs and MPOs to: (1) identify challenges in implementing the MAP-21 CMAQ PM2.5 provisions and (2) assist FHWA in assessing successful implementation of practices capable of addressing the new MAP-21 CMAQ PM2.5 provisions. The survey helped to identify agencies and entities capable of meeting the CMAQ PM 2.5 provisions of MAP-21. Ohio DOT, Delaware Valley Regional Planning Commission, The City of New York and the Chicago Metropolitan Agency for Planning were selected for the development of the CMAQ case studies to describe the innovative practices they have adopted that may serve to address the new MAP-21 CMAQ requirements related to PM 2.5 project implementation.

Also in 2014, FHWA published the “Air Quality and Congestion Mitigation Measure Outcomes Assessment Study: Final Technical Report.” MAP-21 directed the U.S. Department of Transportation (DOT) to fund an air quality and congestion mitigation measure outcome study to examine the outcomes of actions funded under the CMAQ program since the enactment of SAFETEA-LU. The study focused on three areas: (1) assess and document estimated emission reduction, air quality, and human health impacts of federally supported surface transportation actions intended to reduce emissions or lessen traffic congestion and expand on the base of empirical evidence on those impacts; (2) increase the knowledge of other information to more accurately understand the validity of current estimation and modeling routines and ways to improve those routines; and (3) increase the knowledge of factors determining the human health changes associated with these transportation actions.

In 2008 and 2009, FHWA published the “SAFETEA-LU 1808 CMAQ Evaluation and Assessment Phase I” and “SAFETEA-LU 1808 CMAQ Evaluation and Assessment Phase II” final reports, respectively. In SAFETEA-LU Section 1808, Congress required the U.S. Department of Transportation, in consultation with the U.S. Environmental Protection Agency (EPA), to evaluate and assess the direct and indirect impacts of a representative sample of CMAQ-funded projects on air quality and congestion levels. The Phase I study analyzed 67 CMAQ-funded projects, using data supplied by states and MPOs in the FHWA CMAQ database. The Phase I study examined the estimated impacts of CMAQ projects on emissions of transportation-related pollutants, including carbon monoxide (CO), ozone precursors – oxides of nitrogen (NOx) and volatile organic compounds (VOCs) – and particulate matter (PM10 and PM2.5), as well as on



traffic congestion and mobility. The Phase II study focused on exploring different practices and approaches that select agencies nationwide use in CMAQ project selection and implementation. The Phase II study conducted 1-day site interviews with MPOs and state DOTs at seven locations around the country. The Phase II study highlights effective CMAQ implementation practices and identifies benefits, challenges, and opportunities encountered by the agencies interviewed as they program CMAQ funds from the information collected and analyzed during the site visit interviews.

## Project Type Prioritization

The most recent FHWA CMAQ Guidance<sup>1</sup> provides information related to eligible projects and programs that are described under general project type categories. The CMAQ project type categories are shown below in Table 1.

**Table 1. CMAQ General Project Type Category List**

<b>CMAQ General Project Type Categories</b>
Diesel Engine Retrofits & Other Advanced Truck Technologies
Idle Reduction
Congestion Reduction & Traffic Flow Improvements
Freight/Intermodal
Transportation Control Measures (TCM)
Transit Improvements
Bicycle and Pedestrian Facilities and Programs
Travel Demand Management
Public Education and Outreach Activities
Transportation Management Associations
Carpooling and Vanpooling
Carsharing
Extreme Low-Temperature Cold Start Programs
Training
Inspection/Maintenance (I&M) Programs
Innovative Projects
Alternative Fuels and Vehicles
Installation of vehicle-to-infrastructure communications equipment*

\* This category was added under the FAST Act and is included in the FHWA CMAQ Guidance

It was not feasible for NCHRP 25-25 Task 108 to cover all eligible CMAQ project types or develop default inputs for all project types covered in FHWA CMAQ Toolkit within the resources and schedule of

<sup>1</sup> The Congestion Mitigation and Air Quality (CMAQ) Improvement Program Under the Moving Ahead for Progress in the 21st Century Act INTERIM PROGRAM GUIDANCE November 12, 2013, [https://www.fhwa.dot.gov/environment/air\\_quality/cmaq/policy\\_and\\_guidance/2013\\_guidance/cmaq2013.pdf](https://www.fhwa.dot.gov/environment/air_quality/cmaq/policy_and_guidance/2013_guidance/cmaq2013.pdf)

this project. Therefore, the research team conducted a prioritization assessment of the project types for which additional default inputs would be the most beneficial for users.

## PRIORITIZATION METHODOLOGY

The project type prioritization effort analyzed the latest three years (2014- 2016) of complete data from the FHWA's CMAQ Public Access System to determine the most common CMAQ project types. The research team also reviewed the currently available and in development CMAQ Toolkit Tools,<sup>2</sup> CMAQ Cost Effectiveness Tables<sup>3</sup> (which identify the project types with the strongest cost-effectiveness), and FHWA's 2014 Air Quality and Congestion Mitigation Measure Outcomes Assessment Study<sup>4</sup> (which included an assessment of CMAQ project types by location, project sub-type, cost and emission reductions).

The CMAQ Public Access System<sup>5</sup> was used to determine the overall counts of CMAQ project types. In total, for project years 2014 through 2016, 6,571 CMAQ projects were listed in the CMAQ Public Access System. The research team conducted several iterations of matching the CMAQ Public Access System projects to a list of typical CMAQ project types. Although State DOTs are required to report all CMAQ projects in the CMAQ Public Access System, there are not standardized protocols for listing detailed project descriptions of project types into the database. Most entries in the CMAQ Public Access System will include the general project type category for the project (project type category listed in Table 1), however there are several other fields that may or may not contain more detailed project information. Out of the 6,571 projects identified in the CMAQ Public Access System for the years 2014 through 2016, the research team was able to classify 5,545 of them.

The next step in project type prioritization process was to determine if methodologies had been developed for each project type. The CMAQ Toolkit, CMAQ Cost Effectiveness Tables, and FHWA's 2014 Air Quality and Congestion Mitigation Measure Outcomes Assessment Study were reviewed to determine what project types had established methodologies. Table 2 lists the total number of CMAQ projects by CMAQ project type and if methodologies have been established to quantify emissions impacts.

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<sup>2</sup> CMAQ Toolkit: [https://www.fhwa.dot.gov/environment/air\\_quality/cmaq/toolkit/](https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/)

<sup>3</sup> CMAQ Cost Effectiveness Tables:

[https://www.fhwa.dot.gov/environment/air\\_quality/cmaq/reference/cost\\_effectiveness\\_tables/costeffectiveness.pdf](https://www.fhwa.dot.gov/environment/air_quality/cmaq/reference/cost_effectiveness_tables/costeffectiveness.pdf)

<sup>4</sup> CMAQ 2014 Assessment Study:

[https://www.fhwa.dot.gov/environment/air\\_quality/cmaq/research/outcomes\\_assessment/technical\\_report/airquality\\_final.pdf](https://www.fhwa.dot.gov/environment/air_quality/cmaq/research/outcomes_assessment/technical_report/airquality_final.pdf)

<sup>5</sup> CMAQ Public Access System: [https://fhwaapps.fhwa.dot.gov/cmaq\\_pub/](https://fhwaapps.fhwa.dot.gov/cmaq_pub/)

**Table 2. CMAQ General Project Type Category List**

Project Type	CMAQ Public Access System Count (2014-2016)	CMAQ Toolkit Tool Status	CMAQ Toolkit Methodology	CMAQ Cost-effectiveness Report Methodology	2014 Assessment Study Methodology
Intersection Improvements	2361	Tool complete	Y	Y	Y
Pedestrian Paths	952	Tool in development	Y	Y	Y
Facilities Construction	300	No tool	N	Y	N
New Transit Vehicles	261	Tool complete	Y	Y	Y
Incident Management System	214	No tool	Y	Y	Y
Marketing	182	No tool	N	N	Y
Bike Lanes	151	Tool complete	Y	Y	Y
Roundabouts	137	Tool complete	Y	Y	Y
Operating Assistance	113	No tool	N	Y	Y
Park and Ride	106	No tool	Y	Y	Y
Traffic Operation Centers	104	No tool	N	Y	Y
Guaranteed Ride Home Programs	94	No tool	N	N	N
Freeway Management Systems	72	No tool	Y	N	Y
Alternate Fuel (some states)	42	Tool complete	Y	Y	Y
Traffic Synchronization	42	Tool complete	Y	Y	Y
Bus Replacement	40	Tool complete	Y	Y	Y
Bike Sharing	38	Tool complete	Y	Y	N
Equipment Purchase	36	No tool	N	N	Y
Street Sweeping	26	Tool complete	N	N	Y
Bike Racks	25	Tool complete	Y	Y	N
Alternative to Diesel Engines and Engine Replacement	23	Tool complete	Y	Y	Y
Fringe Parking	22	No tool	N	N	N
I&M Program Development	21	No tool	N	N	N
Street Paving	21	Tool complete	N	N	Y
Facility rehabilitation	19	No tool	N	Y	N
Car sharing	16	No tool	N	Y	Y
After Treatment Hardware/Devices	13	No tool	N	N	Y
New stations	12	No tool	N	Y	N
Ramp Metering	11	No tool	Y	Y	Y
On-Board Emissions Control Devices	10	No tool	N	N	Y
New transfer facilities	8	No tool	N	N	N

Project Type	CMAQ Public Access System Count (2014-2016)	CMAQ Toolkit Tool Status	CMAQ Toolkit Methodology	CMAQ Cost-effectiveness Report Methodology	2014 Assessment Study Methodology
Diesel Engine Retrofits	7	Tool complete	Y	Y	Y
Exhaust Retrofit	7	Tool complete	Y	Y	Y
Telecommuting/Teleworking	7	No tool	N	N	N
Flexible Work Schedules	6	No tool	N	N	N
Heavy-Duty Vehicle Retirement Program	5	No tool	N	Y	Y
Hybrid Vehicles	5	No tool	N	N	Y
Support Facilities	5	No tool	N	Y	N
Plug-Ins	4	Tool in development	Y	Y	N
Traffic Calming Measures and Outreach	4	No tool	N	Y	Y
Near/On-Dock Rail	3	No tool	N	N	N
Transit Fare Subsidies	3	No tool	N	Y	N
Electronic Toll System	2	No tool	N	N	Y
Locomotive Retrofit	2	Tool in development	Y	N	N
Parking Pricing	2	No tool	N	N	N
Performance-based Parking	2	No tool	N	N	Y
Publicly-owned fuel Vehicle Purchase	2	No tool	N	N	N
Shuttle Services	2	No tool	N	Y	Y
Auxiliary Power Units	1	Tool complete	Y	Y	Y
Fueling Facilities	1	No tool	Y	Y	N
Heavy-Duty Container Handling Equipment	1	Tool in development	N	Y	N
Large-scale Gantry Cranes	1	Tool in development	N	Y	N
New terminals	1	No tool	N	N	N
Alternate Fuel/Vehicles/Fueling Facilities	0	Tool complete	Y	Y	Y
Bicycle/Pedestrian	0	Tool complete	Y	Y	Y
Commute Strategies	0	No tool	N	Y	Y
Diverging Diamond Interchange	0	No tool	Y	Y	Y
Dust Mitigation	0	Tool complete	Y	Y	Y
Extreme Low-Temperature Cold Start Programs	0	No tool	Y	Y	N
Freight/Intermodal i.e. mode shift to rail/maritime	0	No tool	Y	Y	Y
High-Occupancy Vehicles and Managed Lanes	0	Tool in development	Y	Y	Y
Idle Reduction	0	Tool complete	Y	Y	Y
Intelligent Transportation Systems	0	No tool	Y	Y	Y
New Bus Services	0	Tool complete	Y	Y	Y

Project Type	CMAQ Public Access System Count (2014-2016)	CMAQ Toolkit Tool Status	CMAQ Toolkit Methodology	CMAQ Cost-effectiveness Report Methodology	2014 Assessment Study Methodology
New Rail Services	0	No tool	Y	Y	Y
Public Education/Outreach	0	No tool	N	N	Y
Ridesharing i.e. carpool/vanpool	0	Tool complete	Y	Y	Y
Roadway Improvements	0	No tool	N	Y	Y
Traffic Signalization	0	Tool complete	Y	Y	Y
Alternative Fuel Bus Replacement	0	Tool complete	Y	Y	Y
Core Heaters	0	No tool	N	Y	N
Direct Fired Heaters	0	Tool complete	Y	Y	Y
Electric Outlet Installation	0	Tool complete	Y	Y	N
Engine Rebuilding	0	No tool	N	N	Y
Engine Retrofit/Replacement	0	Tool complete	Y	Y	Y
Fleet Conversion	0	Tool complete	Y	Y	Y
Improve Cab/Trailer/Tire Efficiency	0	No tool	N	N	N
Inland Transshipment Ports	0	No tool	N	Y	N
Purchase or Retrofit of Airport Handling Equipment	0	No tool	N	Y	N
Regional Multimodal Traveler Information Systems	0	No tool	Y	Y	Y
Software and Training	0	No tool	N	N	N

## FINAL PROJECT TYPES

After analyzing the CMAQ Public Access System and the established methodologies for CMAQ project types, the research team proceeded with development of the Project Type Tools listed in Table 3. These 16 basic project types include the most common project types within the CMAQ Public Access System, as well as other tools of interest with CMAQ toolkits available, and rich sources of potential defaults available from analysis of these project types in the cost effectiveness report and/or CMAQ assessment study.

**Table 3. List of Project Types and Corresponding CMAQ Data**

Project Type	NCHRP 25-25 Task 108 Spreadsheet Tool Name(s)	CMAQ Public Access System Count (2014-2016)	CMAQ Toolkit Tool Status	CMAQ Toolkit Methodology	CMAQ Cost-effectiveness Report Methodology	2014 Assessment Study Methodology
Intersection Improvements	Intersection Improvements	2361	Tool complete	Y	Y	Y
Pedestrian Paths	Bicycle and Pedestrian Improvement Projects	952	Tool complete	Y	Y	Y
New Transit Vehicles	New Transit Buses	261	Tool complete	Y	Y	Y
Bike Lanes	Bicycle and Pedestrian Improvement Projects	151	Tool complete	Y	Y	Y
Roundabouts	Roundabouts	137	Tool complete	Y	Y	Y
Traffic Synchronization	Signal Synchronization	42	Tool complete	Y	Y	Y
Bus Replacement	Bus Replacement	40	Tool complete	Y	Y	Y
Bike Sharing	Bicycle and Pedestrian Improvement Projects	38	Tool complete	Y	Y	N
Street Sweeping	Street Sweeping	26	Tool complete	Y	N	Y
Alternative to Diesel Engines and Engine Replacement	Alternative to Diesel Engines and Engine Replacement	23	Tool complete	Y	Y	Y
Street Paving	Street Paving	21	Tool complete	Y	N	Y
Diesel Engine Retrofits	Diesel Engine Retrofits	7	Tool complete	Y	Y	Y
Idle Reduction	Diesel Idle Reduction	0	Tool Complete	Y	Y	Y
New Bus Services	New Bus Service	0	Tool complete	Y	Y	Y
Ridesharing	Carpooling and Vanpooling	0	Tool complete	Y	Y	Y
High-Occupancy Vehicles and Managed Lanes	Managed Lanes	0	Tool in development	Y	Y	Y

# Tool Development Process

## OVERVIEW

Each Project Type Tool contains multiple worksheets, including user interface, calculations, emission rates tabs. The primary data sources for the Project Type Tools are:

- U.S. Environmental Protection Agency’s Motor Vehicle Emissions Simulator (MOVES), version 2014b<sup>6</sup>
- Argonne National Laboratory’s Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool, 2017 version<sup>7</sup>
- FHWA’s CMAQ Toolkit – the CMAQ Toolkit<sup>8</sup> was used as a resource for tool methodology and activity inputs for the Task 108 tools. Detailed user guides and emissions data documentation were developed for each CMAQ Toolkit tool.

AFLEET was used to obtain conversion factors for different fuels in the Carpool and Vanpool tools and the Diesel Alternatives and Replacements tool. Refer to the AFLEET Methodology section below for more detail on the AFLEET factors and specific fuels and vehicle types.

All Project Type Tools output the following emissions reductions:

- Carbon monoxide (CO)
- Nitrogen oxide (NO<sub>x</sub>)
- Particulate matter with a diameter less than 2.5 micrometers (PM<sub>2.5</sub>)
- Particulate matter with a diameter less than 10 micrometers (PM<sub>10</sub>)
- Volatile organic compounds (VOC)

All outputs are reported in kilograms per day (kg/day) and positive output values represent emission reductions and negative output values represent emission increases. It is possible to have emission reductions for one pollutant and emission increases (i.e., disbenefits) for another pollutant depending on the inputs associated with a project type.

The Simplified Toolkit can model emissions reductions for any project evaluation year between 2020 and 2040. A project evaluation year is the anticipated year project will be deployed or built.<sup>9</sup>

The following sections describe the interpolation method to calculate emissions benefits for all project evaluation years, the MOVES modelling process, and design considerations for the spreadsheet tools.

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<sup>6</sup> EPA MOVES: <https://www.epa.gov/moves>

<sup>7</sup> AFLEET: <https://afleet-web.es.anl.gov/home/>

<sup>8</sup> CMAQ Toolkit: [https://www.fhwa.dot.gov/environment/air\\_quality/cmaq/toolkit/](https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/)

<sup>9</sup> Consistent with MOVES, the range of model years which can be assessed using the Simplified Toolkit is 30 years prior to the project evaluation year.

## SPREADSHEET TOOL DESIGN

The following considerations guided the development of the spreadsheet tools.

1. **Include default activity data to simplify the analysis process.** To the extent that supporting data are available, the tools provide typical inputs for the CMAQ project type under consideration. This will save users lacking their own detailed activity data substantial time/expense and allow for quick emissions reduction estimates based on preliminary project scope parameters. See the User Guide for a list of default activity inputs.
2. **Flexibility for users to incorporate their own data.** The design of the tools allows users to customize inputs (i.e., input locally-specified values to replace the defaults provided) so as to provide the users the option of accepting all the defaults or changing one or more of the defaults to calculate emissions reductions based on locally-specified project or program characteristics or activity data.
3. **Incorporate interpolation to improve the tool's granularity.** For all project/program types, the tools include the capacity to interpolate between provided values. For example, emission rates are provided for 2020, 2025, 2030, 2035, and 2040, and the tools can interpolate values for a 2037 time horizon.

## EVALUATION YEAR INTERPOLATION

The Project Type Tools use an interpolation method to calculate emission rates for project types where the evaluation year is a primary factor in calculating the emission reductions. In order to obtain emission rates for project evaluation years between 2020 and 2040, 5 year increments were modeled using MOVES2014b (e.g., the years 2020, 2025, 2030, 2035, and 2040 were modeled).

A matching algorithm within the tools uses the user-input project year and determines the upper bound emission rate and lower bound emission rate and interpolates between the emission rates to obtain emissions rates for project years within the five-year increments of modeled data. For example, if the user chooses a year of 2027 then the upper bound emission rates will be pulled from 2030 MOVES output data and the lower bound emission rates will be pulled from the 2025 MOVES output data.

The interpolation method used in the tools can be described by the equation below:

$$ER_y = ER_{yl} + (y - yl) \frac{ER_{yu} - ER_{yl}}{yu - yl}$$

where:

$ER_y$  = The emission rate at the user-input year

$ER_{yl}$  = The emission rate at the lower bound year

$ER_{yu}$  = The emission rate at the upper bound year

$y$  = The user input project evaluation year

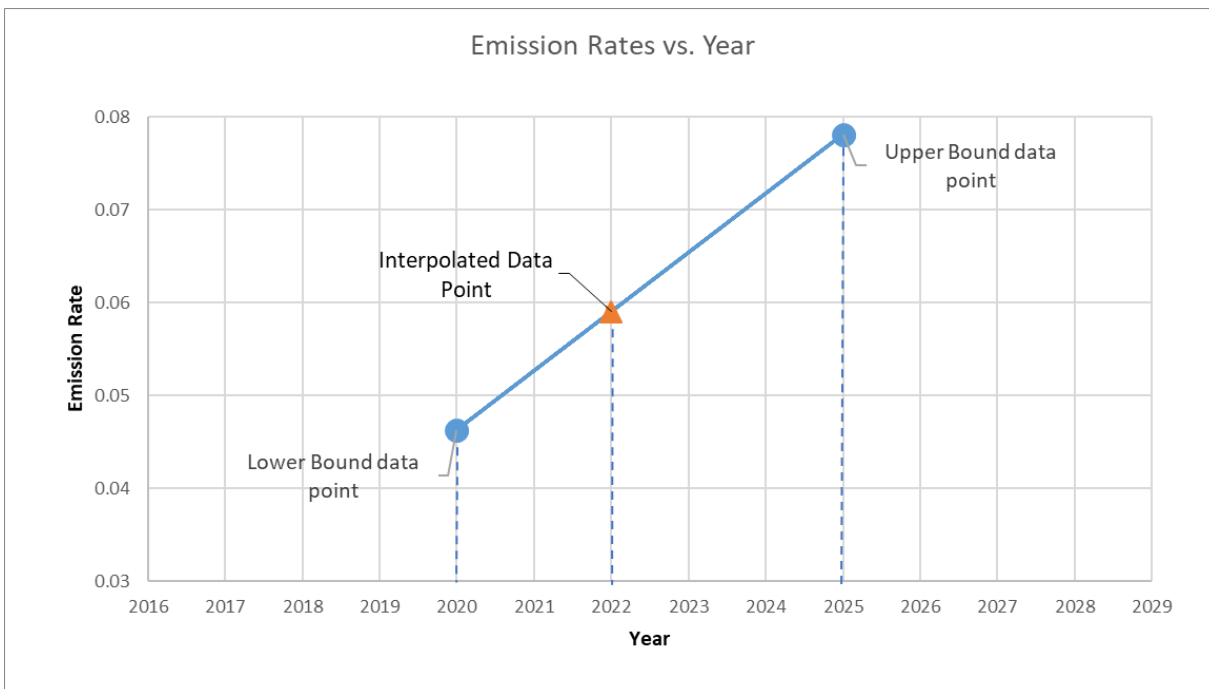


$yl$  = The lower bound year in the tool data

$yu$  = The upper bound year in the tool data

The interpolation method relies on the assumption that the emission rates at years between the years available in the data set change linearly with time. While this results in an approximation of the emission rates at the input project year, it allows emission rates to be calculated without inclusion of the data for every project year included in the tool. The assumption of linearity between data points is illustrated in **Error! Reference source not found.**

**Figure 1. Linear Interpolation in the Project Type Tools**



For some project types, the model year of a vehicle being purchased or implemented in a project is an important factor in determining the relevant emission rates for that vehicle. Since emissions data does not exist for vehicles in years prior to their introduction year, it is impossible to perform an interpolation if the user inputs a model year within the same 5 year period as the project evaluation year. To alleviate this issue, the emissions rates for introduction years for every model year greater than 2020 is included in the tool data for tools which require the user to choose a model year to calculate emissions benefits.

A comparison equation in the tools decides which lower bound project evaluation year to use in the interpolation. If the model year is not in the same 5 year period as the project evaluation year, the normal lower bound project year is used in the interpolation. However, if the model year falls in the same 5 year period, the tool uses the introduction year of that model year as the lower bound of the interpolation. In this way, the amount of data in the tool is reduced significantly from having all model years for every project evaluation year, while preserving the interpolation functionality and providing estimated results for all years between 2020 and 2040.

## MOVES EMISSIONS ANALYSES

MOVES run specifications were setup for each required run to obtain the necessary output format, units, and level disaggregation. Most tools used national level inventory MOVES simulations to calculate emissions and activity inventories. For tools that did not focus on a specific vehicle type, or model year, national average fleet mixes were used and emissions data were aggregated in post processing to obtain emission factors averaged across the entire fleet.

Some of the tools required emissions factors to be determined by speed bin, so project level runs were completed for these tools. Because some of the tools developed required project level runs, the input databases for these runs used a national average default region. Project-level inputs included details on meteorology, vehicle age distribution, and I/M programs based on national averages. The team used the most efficient process to complete the MOVES runs by developing programming scripts to run batch MOVES runs, set up input files, and interpret output data.

Once the MOVES runs are completed, post-processing analyses were performed on the resulting output databases to obtain emission results in the format required for the spreadsheet tools. For example, to obtain emission rates for emissions that are generated on a per-miles basis (running exhaust, tirewear, brakewear, and crankcase running exhaust), an emission rates post-processing script was applied. Similarly, start emissions were determined on a per vehicle basis.

The post-processing approach was designed as simply and transparently as possible to facilitate future updates with potential future versions of the MOVES model. The research team has used a similar approach with its work for the FHWA Toolkit by keeping a consistent table format “map” that can be updated with new MOVES emission rates in the future. Further details on post-processing of the MOVES output data are given in the Post Processing and Tool Updates section below.

All tools utilize running exhaust and running crankcase emissions processes in MOVES. The tools that involve a diversion in passenger vehicle trips (New Transit Buses, Carpooling and Vanpooling, and Bike/Pedestrian tools) include start emissions processes for exhaust and crankcase. The Diesel Idle reduction Tool includes extended idle exhaust emissions and auxiliary power exhaust processes.

## Post-Processing and Tool Updates

The design of the NCHRP Simplified Toolkit facilitates updates to the underlying emissions data, in case of new model versions of MOVES or AFLEET. To update data, select the ‘Data’ tab for the tool of interest (e.g., BikePedData or TransitBusReplaceData) in Excel. Aggregated and post-processed MOVES output data or AFLEET conversion factors can be copied and pasted into the tool using the same format and aggregation level (column names for model year, road type, etc.).

## MOVES METHODOLOGY

To obtain emission rates from MOVES run output databases, the emissions quantities for the relevant vehicle types, fuel types, pollutants, and road types were joined with the activity quantities. Dividing the emission quantity by the activity quantity gives an estimate of the average emission factor in each

evaluation year for a model year and pollutant type. For all the tool data, the pollutant ID's from the MOVES output data for brakewear and tirewear particulate matter emissions were set as the same pollutant IDs for exhaust particulate matter emissions. In this way, an overall aggregated particular matter emission factor was obtained. More specific aggregation and post processing techniques are described below for each tool.

**Table 4. Aggregation and Post-Processing Techniques in the Simplified Toolkit**

Tool	Aggregation and Post-processing techniques used in each tool
Transit Bus Replacement and New Transit Buses	<ul style="list-style-type: none"> <li>For intermediate years (all years besides 2020, 2025, 2030, 2035, 2040), data are only included for model years introduced in that year, to account for interpolation issues when choosing model years within those ranges. More details are described in the "Evaluation Year Interpolation" Section.</li> <li>MOVES does not include electric bus emissions. Therefore, brake and tire wear PM emissions and activities are taken from gasoline transit buses. Emission rates for all other pollutants are assumed to be 0.</li> <li>For this tool, national average distributions of the road types on which a bus drives are used to calculate emissions on each road type before summing. VMT activity rates on each road are divided by the total VMT driven by a year, model year, and fuel type combination.</li> <li>Passenger vehicle data are separated into running emissions and start emissions. All running emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. All start emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. Start emission rates are assigned a processID of 7 in MOVES.</li> </ul>
New Bus Services	<ul style="list-style-type: none"> <li>For intermediate years (all years besides 2020, 2025, 2030, 2035, 2040), data are only included for model years introduced in that year, to account for interpolation issues when choosing model years within those ranges. More details are described in the "Evaluation Year Interpolation" Section.</li> <li>This tool uses national average distributions of model years, road types, and fuel types of transit buses. These are obtained by dividing the population VMT for specific combinations of these IDs by the total VMT. Multiplying these distributions together for a specific model year, road type, and fuel type combination gives the share of the total VMT for that combination in a fleet of transit vehicles.</li> <li>Passenger vehicle data are separated by running emissions and start emissions. All running emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. All start emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. Start emission rates are assigned a processID of 7</li> </ul>
Diesel Retrofits	<ul style="list-style-type: none"> <li>Only diesel fuel types used</li> <li>Emission factor data only includes running emissions factors</li> <li>For intermediate years (all years besides 2020, 2025, 2030, 2035, 2040), data are only included for model years introduced in that year, to account for interpolation issues when choosing model years within those ranges. More details are described in the "Evaluation Year Interpolation" Section.</li> </ul>
Diesel Idle Reduction	<ul style="list-style-type: none"> <li>Only diesel fuel types used</li> <li>Emission factors are computed using operating hour activity data instead of distance traveled. This facilitates emissions calculations using the number of hours idling instead of running VMT</li> </ul>
Alternative to Diesel Engine and Engine Replacement	<ul style="list-style-type: none"> <li>Only diesel fuel types used</li> <li>Emission factor data only includes running emissions factors</li> <li>For intermediate years (all years besides 2020, 2025, 2030, 2035, 2040), data are only included for model years introduced in that year, to account for interpolation issues when choosing model years within those ranges. More details are described in the "Evaluation Year Interpolation" Section.</li> </ul>
Carpooling	<ul style="list-style-type: none"> <li>Passenger vehicle data are separated by running emissions and start emissions. All running emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. All start emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. Start emission rates are assigned a processID of 7</li> </ul>

Tool	Aggregation and Post-processing techniques used in each tool
Vanpooling	<ul style="list-style-type: none"> <li>• Carpool passenger vehicle data are used to calculate light duty vehicle emissions reduced as a result of the vanpool project</li> <li>• Vanpool data includes passenger truck, light commercial truck, and school bus data.</li> <li>• As with passenger vehicle data, emissions factors are calculated for both miles traveled and starts. All running emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. All start emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year.</li> </ul>
Bicycle and Pedestrian Improvement Projects	<ul style="list-style-type: none"> <li>• Passenger vehicle data are separated by running emissions and start emissions. All running emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. All start emissions processes are combined to obtain a total emission factor for each pollutant in an evaluation year. Start emission rates are assigned a processID of 7.</li> </ul>
Street Sweeping	<ul style="list-style-type: none"> <li>• Exhaust emission rates for gasoline, diesel, and clean/alternative fuel street sweepers obtained using EPA's Emission Standards for Heavy-Duty Highway Engines and Vehicles.</li> </ul>
Street Paving, Signal Synchronization, Intersection Improvements, Roundabouts, and Managed Lanes	<ul style="list-style-type: none"> <li>• Project level moves runs used to obtain emission rates at certain speeds (see included project level input databases and MOVES runspecs). Emission rates are separated by light duty and heavy duty vehicles. Light duty vehicles are defined as source type ids 21, 31, and 32. All other source type ids are defined as heavy-duty vehicles. Emission and activity quantities are aggregated for these groups. Light duty vehicles are given a classID of 1, and heavy-duty vehicles are given a classID of 2. The emission factors in these emissions data represent averages for these vehicle categories at the specific speeds shown in the data tables.</li> </ul>

## AFLEET METHODOLOGY

The Alternative Fuel Emission Factor Multipliers from AFLEET 2016's Background Data tab were used directly in the Simplified Toolkit for alternative fuel emission rates that were not available in MOVES. Table 5 below details which vehicle type and fuel type combinations used MOVES data or AFLEET emissions factor multipliers to calculate the emission factors used in the tools that used alternative fuels.

**Table 5. MOVES and AFLEET Data Used in the Simplified Toolkit**

Vehicle Source Type	Fuel Type										
	BEV	Dual Fuel	B100	B20	CNG	E85	FCV	HEV	HHV	LNG	LPG
Passenger Car	M		A	A	A	M	M	A		A	A
Passenger Truck	M		A	A	A	M	M	A		A	A
Light Commercial Truck	M		A	A	A	M	M	A		A	A
School Bus			A	A	A	A		A	A	A	A
Refuse Truck		A	A	A	A			A	A	A	
Single Unit Short-haul Truck		A	A	A	A	A		A	A	A	A
Single Unit Long-haul Truck		A	A	A	A	A		A	A	A	A
Combination Short-haul Truck		A	A	A	A			A	A	A	
Combination Long-haul Truck		A	A	A	A			A	A	A	
M = MOVES emission rates, A = AFLEET factors combined with conventional fuel emission rates											

The baseline emission factor used for source types IDs 21, 31, and 32 was gasoline, whereas for heavy-duty vehicles, source type IDs 43 and above, the baseline factor was for diesel fuel. Applying the AFLEET emission factor multiplier for the alternative fuel and vehicle type to the relevant baseline fuel will give an estimate of the emission factor for that vehicle type and fuel type combination.

All MOVES modeling files (runspecs, output databases, etc.) will be made available on the NCHRP-25-25 project website as part of the final deliverables for this project. The MOVES runspecs used in the various tools are listed in Table 6.

**Table 6. MOVES RunSpec and Output Databases Used in the Simplified Toolkit**

Tool	Applicable MOVES Runspec and Output Database Name
Transit Bus Replacement	transitvehicles_2020_2040_allyears,
New Bus Services	transitvehicles_2020_2040_allyears, passengervehicles_2025303540
New Transit Buses	transitvehicles_2020_2040_allyears, passengervehicles_2025303540
Diesel Retrofits	diesel_2020_2040_allyears
Diesel Idle Reduction	diesel_2020_2040_allyears
Alternative to Diesel Engines and Engine Replacement	diesel_2020_2040_allyears
Carpooling	passengervehicles_2025303540
Vanpooling	passengervehicles_2025303540, vanpooling_2020_2040_allyears
Bicycle-Pedestrian Projects	passengervehicles_2025303540
Street Sweeping	MOVES not used for emissions data for street sweepers
Street Paving	streetpaving_2025303540
Signal Synchronization	ProjectLevelRuns
Intersection Improvements	ProjectLevelRuns
Roundabouts	ProjectLevelRuns
Managed Lanes	ProjectLevelRuns

## Comparison to FHWA CMAQ Toolkit

The research team compared the output of the Simplified Toolkit with output from the corresponding tool in the FHWA Toolkit (see comparisons in the appendix). In general, these comparisons show that the Simplified Toolkit and FHWA Toolkit results are in good agreement. Note these sensitivity tests were meant to be comparisons with an established set of tools, not full verification or validation of the NCHRP Simplified Toolkit. In order to fully validate the results output by the Simplified Toolkit, emissions measurements and results from actual field tests on real world vehicles would be needed to validate the outputs of the tool (such an effort was well outside the scope of this study).

The interpolation used in the Simplified Toolkit introduces some discrepancies in comparisons for project years that fall in between the modeled years (e.g., 2021 would require interpolation). The interpolation approach helped to expedite tool development and reduces computational time in the tool, but does introduce some errors depending on the year input by a user. Some of the older FHWA tools (e.g., Carpool/Vanpool) use an older version of MOVES (2014a), which also causes some discrepancies when comparing with the Simplified Toolkit (version 2014b).

The differences between the Simplified Toolkit and FHWA Toolkit New Bus Services and New Transit Buses tools can be primarily attributed to the inclusion of starts in the Simplified tool’s passenger vehicle

emissions (the FHWA tool considers running emissions only). The estimation of emissions benefits by interpolation in the Bus Replacement, New Transit Buses, and New Bus Services tools is also generally less accurate than in other tools. This is due to significant changes in transit bus emission rates between some evaluation years.

For the traffic flow improvement tools (e.g., Intersection Improvements, Signal Synchronization, Managed Lanes), the differences between the Simplified and FHWA Toolkits are considerable (with and without interpolation). This is particularly evident in the Signal Synchronization Tool and the PM results for the Managed Lanes Tool. The Simplified Toolkit traffic flow tools require fewer inputs compared with the FHWA tools and use a simplified methodology. As part of the Simplified Toolkit development, some errors were discovered in the FHWA Toolkit that are being corrected for a future version of the FHWA Toolkit currently under development (anticipated to be publicly released in fall 2019).

As mentioned previously, some FHWA tools involving passenger vehicle trip diversions (transit bus tools, as well as bicycle and pedestrian tools) do not account for a reduction in start emissions due to trip diversions. All tools in the Simplified Toolkit that use light duty passenger vehicle emission factors now account for start emissions reductions from trip diversions, so the emissions reductions results in these tools will differ slightly. An error was also found in the aggregation methodology in the Carpool/Vanpool FHWA tool in the passenger vehicle PM emission factors. Thus, the aggregated PM emission factors are substantially different in the Simplified Toolkit. This will be corrected in the updated version of FHWA's Toolkit anticipated in fall 2019.

Despite the differences between outputs of the Simplified Toolkit and FHWA Toolkits for some tools, the Task 108 development team is confident in the calculation methodologies and emissions data used in the Simplified Toolkit. Once the FHWA tools are updated and any errors corrected, the team expects the two sets of results to be in considerably closer alignment.

## CONCLUSION

The NCHRP 25-25 Simplified Toolkit allows for streamlined determination of emissions benefits from a wide range of CMAQ-eligible project types. The tools were designed specifically for users with limited air quality modelling experience and limited input data available. The averages values given in the default table allow these users to gain a general idea of the range of emissions benefits that result from transportation projects.

The Simplified Toolkit was developed relatively quickly compared to FHWA's existing CMAQ Toolkit, due to use of simplified methodology and user interfaces. The Simplified Toolkit was also designed to allow for future updates with new emissions data from updated MOVES versions or other sources.

Comparisons between the Simplified and FHWA Toolkits show generally good agreement between the two platforms. Differences can primarily be attributed to simplified methodologies including interpolation in the NCHRP tools, differences in emissions data aggregation methodologies, and potential errors in the FHWA Toolkit calculations.

Future research areas may include updating comparisons once planned updates to the FHWA Toolkit are complete, development of additional tools to cover project types such as non-road equipment and automated vehicles, and additional error checking and improvements to the Simplified Toolkit user interfaces.



## Appendix: NCHRP Simplified Toolkit and FHWA Toolkit Comparisons

Note that red values in the tables below indicate an emissions disbenefit (i.e., an increase in emissions).

### BUS REPLACEMENT

#### Example 1, no interpolation applied

INPUTS:

Project Year: 2020

Bus Daily VMT: 50 (annual = 18,250 for FHWA tool)

Model of bus to be replaced: 2008

Fuel type of bus to be replaced: Diesel

Model year of bus to be purchased: 2019

Fuel type of bus to be purchased: CNG

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	-0.1268	0.0015	0.0016	0.1602	0.0034
FHWA Output	-0.1229	0.0015	0.0016	0.1602	0.0015
Percent Difference	3.17%	0.00%	0.00%	0.00%	55.88%

#### Example 2, interpolation

INPUTS:

Project Year: 2021

Bus Daily VMT: 50

Model of bus to be replaced: 2008

Fuel type of bus to be replaced: Diesel

Model year of bus to be purchased: 2019

Fuel type of bus to be purchased: CNG

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	-0.1653	0.0015	0.0016	0.1577	0.0024
FHWA Output	-0.1228	0.0015	0.0016	0.1602	0.0015
Percent Difference	34.61%	0.00%	0.00%	1.59%	37.50%

## NEW TRANSIT BUSES TOOL COMPARISON

### Example 1, no interpolation applied

#### INPUTS:

Project Year 2020

Model Year 2019

Passenger car one way trips diverted (NCHRP) = 650

Passenger car average trip distance (NCHRP) = 6

Passenger vehicle miles traveled before (FHWA) = 3,900

Passenger vehicle miles traveled after (FHWA) = 0

New bus fuel type = Gasoline

New bus VMT = 50 (input 0 for before in FHWA)

Days operated per year = 1

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	12.5259	0.0392	0.1389	1.0202	0.5746
FHWA Output	12.6353	0.0387	0.1400	1.0303	0.5867
Percent Difference	0.87%	1.29%	0.79%	0.99%	2.11%

### Example 2, interpolation applied

#### INPUTS:

Project Year 2021

Model Year 2019

Passenger car one way trips diverted (NCHRP) = 650

Passenger car average trip distance (NCHRP) = 6

Passenger vehicle miles traveled before (FHWA) = 3,900

Passenger vehicle miles traveled after (FHWA) = 0

New bus VMT = 50 (input 0 for before in FHWA)

New bus fuel type = Gasoline

Days operated per year = 1

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	11.7791	0.0397	0.1382	0.9227	0.5251
FHWA Output	11.9412	0.0386	0.1456	0.9235	0.5581
Percent Difference	1.36%	2.85%	5.35%	0.09%	6.28%

## NEW BUS SERVICES TOOL COMPARISON

### Example 1, no interpolation applied

#### INPUTS:

Project Year 2020

Before bus VMT = 50

After bus VMT = 100

Passenger car one way trips diverted (NCHRP) = 650

Passenger car average trip distance (NCHRP) = 6

Passenger vehicle miles traveled before (FHWA) = 3,900

Passenger vehicle miles traveled after (FHWA) = 0

Days operated per year = 1

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	12.4975	0.0339	0.1355	0.7849	0.5882
FHWA Output	11.9754	0.0374	0.1386	0.9798	0.5684
Percent Difference	4.36%	9.36%	2.29%	24.83%	3.37%

Example 2, interpolation applied

INPUTS:

Year 2021

Before bus VMT = 50

After bus VMT = 100

Passenger car one way trips diverted (NCHRP) = 650

Passenger car average trip distance (NCHRP) = 6

Passenger vehicle miles traveled before (FHWA) = 3,900

Passenger vehicle miles traveled after (FHWA) = 0

Days operated per year = 1

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	11.7946	0.0332	0.1347	0.7109	0.5425
FHWA Output	11.9412	0.0386	0.1456	0.9235	0.5581
Percent Difference	1.23%	13.99%	8.09%	29.91%	2.88%

**ALTERNATIVE TO DIESEL ENGINES AND ENGINE REPLACEMENT TOOL  
COMPARISON**

Example 1 – No Interpolation

Inputs:

Project Year = 2020

Annual VMT = 10,950

Vehicle Type = Light Commercial Truck

Old Model Year = 2010

New Model Year = 2021

Old Fuel = Diesel

New Fuel = CNG

	CO	PM2.5	PM10	NOx	VOC
NCHRP Tool Output	0.0767	0.0003	0.0003	0.0169	0.0029
FHWA Tool Output	0.0702	0.0002	0.0003	0.0165	0.0028
Percent difference	9.26%	50.00%	0.00%	2.42%	3.57%

Example 2 – Interpolation

Inputs:

Project Year = 2021

Annual VMT = 10,950

Vehicle Type = Light Commercial Truck

Old Model Year = 2010

New Model Year = 2021

Old Fuel = Diesel

New Fuel = CNG

	CO	PM2.5	PM10	NOx	VOC
NCHRP Tool Output	0.0773	0.0003	0.0003	0.0175	0.0030
FHWA Tool Output	0.0714	0.0002	0.0003	0.0167	0.0029
Percent difference	8.26%	50.00%	0.00%	4.79%	3.45%

## DIESEL IDLE REDUCTION TOOL COMPARISON

### Example 1: No Interpolation performed

Inputs:

Year = 2020

Activity = 100

Activity Type = Population

Hoteling Mode = Diesel APU

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	38.98685359	1.237250784	1.397080644	91.8340369	19.71677979
FHWA Output	39.2166245	1.2298871	1.3895915	92.0457708	19.7120744
Percent Difference	0.59%	0.60%	0.54%	0.23%	0.02%

### Example 2: Interpolation performed

Inputs:

Year = 2023

Activity = 100

Activity Type = Population

Hoteling Mode = Diesel APU

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	35.21361957	0.933190919	1.005619257	77.4938472	15.85557279
FHWA Output	35.9183431	0.9165062	0.9710471	77.8115652	15.7532042
Percent Difference	1.96%	1.82%	3.44%	0.41%	0.65%

Example 3: Interpolation performed with different Year and Hoteling technology

Inputs:

Year = 2027

Activity = 100

Activity Type = Population

Hoteling Mode = D-F Heater

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	39.75441555	1.077873422	1.177479462	74.04180842	11.87983582
FHWA Output	39.7585768	1.0783799	1.1780267	74.0382641	11.8837929
Percent Difference	0.01%	0.05%	0.05%	0.00%	0.03%

**CARPOOLING TOOL COMPARISON**

Example 1: No interpolation applied

Inputs:

Project Year = 2020

Centralized pickup/dropoff locations = yes

Average distance to central locations = 10 miles roundtrip for FHWA, 5 miles one way for NCHRP

Vehicles participating = 10

Passengers per carpool vehicle = 3

Average commute distance = 25.2 miles roundtrip for FHWA, 12.6 miles one way for NCHRP

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	0.9528	0.0039	0.0016	0.0735	0.0130
FHWA Output	0.9523	0.0021	0.0023	0.0735	0.0129
Percent Difference	0.05%	85.71%	43.75%	0.00%	0.77%

Example 2: Interpolation applied

Inputs:

Project Year = 2021

Centralized pickup/dropoff locations = yes

Average distance to central locations = 10 miles for FHWA, 5 miles one way for NCHRP

Vehicles participating = 10

Passengers per carpool vehicle = 3

Average commute distance = 25.2 miles roundtrip for FHWA, 12.6 miles one way for NCHRP

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	0.9003	0.0038	0.00163	0.0662	0.0117
FHWA Output	0.8931	0.0019	0.0022	0.0633	0.0109
Percent Difference	0.81%	100.00%	34.97%	4.38%	6.84%

Example 3: Interpolation applied with non-centralized locations

Inputs:

Project Year = 2020

Centralized pickup/dropoff locations = no

Average distance to central locations = 0 miles

Vehicles participating = 10

Passengers per carpool vehicle = 3

Average commute distance = 25.2 miles roundtrip for FHWA, 12.6 miles one way for NCHRP

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	1.9946	0.0071	0.0278	0.1603	0.0676
FHWA Output	1.9936	0.0040	0.0045	0.1603	0.0667
Percent Difference	0.05%	77.50%	83.81%	0.00%	1.33%



## VANPOOLING TOOL COMPARISON

### Example 1: No interpolation applied

Inputs:

Inputs:

Project Year = 2020

Centralized pickup/dropoff locations = Yes

Average distance to central locations = 10 miles

Vehicles participating = 10

Passengers per vanpool vehicle = 3

Vehicle type = mini van

Fuel type = gasoline

Model year = 2020

Average commute distance = 25.2 miles roundtrip for FHWA, 12.6 miles one way for NCHRP

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	0.7854	0.0030	0.0112	0.0654	0.0091
FHWA Output	0.8234	0.0011	-0.0029	0.0654	0.0089
Percent Difference	4.62%	172.73%	125.89%	0.00%	2.20%

## Vanpooling

### Example 2: Interpolation applied

Inputs:

Project Year = 2021

Centralized pickup/dropoff locations = Yes

Average distance to central locations = 10 miles for FHWA, 5 miles one way for NCHRP

Vehicles participating = 10

Passengers per carpool vehicle = 3

Vehicle type = mini van

Fuel type = gasoline

Model year = 2020

Average commute distance = 25.2 miles roundtrip for FHWA, 12.6 miles one way for NCHRP

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	0.7680	0.0028	0.0110	0.0575	0.0074
FHWA Output	0.7645	0.0010	-0.0030	0.0553	0.0070
Percent Difference	0.46%	180.00%	127.27%	3.83%	5.41%

## BICYCLE AND PEDESTRIAN IMPROVEMENT PROJECTS TOOL COMPARISON

### Example 1 – Year 2020

Inputs:

The following example uses an arbitrary reduction in vehicle trips and the national average trip distance.

Project Year	Trip Reductions	National Average Trip Distance
2020	72	2.494

Pollutant	FHWA Tool	NCHRP Tool	Percent Difference
Carbon Monoxide (CO)	0.6480	0.8732	34.75%
Particulate Matter <2.5 µm (PM <sub>2.5</sub> )	0.0021	0.0022	4.76%
Particulate Matter <10 µm (PM <sub>10</sub> )	0.0083	0.0072	13.25%
Nitrogen Oxide (NOx)	0.0560	0.0751	34.11%
Volatile Organic Compounds (VOC)	0.0394	0.0603	53.05%

### Example 2 – Year 2023

Inputs:

Project Year	Trip Reductions	National Average Trip Distance
2023	72	2.494

The table below shows the comparison of outputs between the two tools.

Pollutant	FHWA Tool	NCHRP Tool	Percent Difference
Carbon Monoxide (CO)	0.5311	0.7235	36.23%
Particulate Matter <2.5 µm (PM <sub>2.5</sub> )	0.0019	0.0020	5.26%
Particulate Matter <10 µm (PM <sub>10</sub> )	0.0080	0.0070	12.50%
Nitrogen Oxide (NO <sub>x</sub> )	0.0382	0.0553	44.76%
Volatile Organic Compounds (VOC)	0.0292	0.0468	60.27%

## STREET SWEEPING TOOL COMPARISON

This NCHRP tool does not use project evaluation year as a primary input in the calculations. Therefore, interpolation is not used in the tool. Since the emission rates are only based on model year of the street sweeper, only one comparison is provided as the emission rates data are the same between both tools.

### Example 1: Diesel/alternative/clean street sweeper

Inputs:

Year = 2023

Total yearly traffic VMT on the paved road = 400,000

Total sweeper VMT on the road = 4000

Roadway type = rural restricted access

Sweeper fuel type = diesel alternative clean

Sweeper gross weight = under 14,000

Sweeper model year = 2020

Vehicle weight class distributions: less than 14,000 = .766, over 14,000 = .234

Annual operating hours of the street sweeper fleet = 2,500

Results:

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	-0.2123	7.8402	31.7962	-0.0027	-0.0021
FHWA Output	-0.2123	7.9382	32.1931	-0.0027	-0.0021
Percent Difference	0.00%	1.23%	1.25%	0.00%	0.00%

## STREET PAVING TOOL COMPARISON

The NCHRP Bike-Ped Tool uses the same MOVES run specification, as well as similar aggregation post-processing scheme as the FHWA tool.

### Example 1: No Interpolation performed

Inputs:

Year = 2020

Road surface before paving = Dirt

Moisture condition before paving = Typical

Roadway type = Urban Unrestricted Access

Speed before paving = 20

Speed after paving = 25

Length of roadway = 0.5

Average hourly flow = 1000 (4,380,000 annually)

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	5.6423	599.4459	6010.3327	0.7479	0.1673
FHWA Output	5.6792	599.4638	6010.4781	0.7323	0.1749
Percent Difference	0.65%	0.00%	0.00%	2.09%	4.54%

Example 2: Interpolation performed

Inputs:

Year = 2023

Road surface before paving = Dirt

Moisture condition before paving = Typical

Roadway type = Urban Unrestricted Access

Speed before paving = 20

Speed after paving = 25

Length of roadway = 0.5

Average hourly flow = 1000 (4,380,000 annually)

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	4.7610	599.4335	6010.3191	0.5963	0.1221
FHWA Output	4.7589	599.4503	6010.4631	0.5607	0.1226
Percent Difference	0.04%	0.00%	0.00%	5.97%	0.41%

**SIGNAL SYNCHRONIZATION TOOL COMPARISON**

The examples below show a comparison of the NCHRP toolkit with the developed CMAQ Toolkit Traffic Signal Synchronization Tool. The NCHRP Signal Tool uses the same MOVES run specification, as well as the same data aggregation post-processing scheme as the FHWA tool.

Example 1: No Interpolation performed

Inputs:

Year = 2020

Road Type = Urban

Corridor Length = 1

Number of Intersections = 6

Number of Lanes = 2

Speed Limit = 35

Signal Cycle Length = 90

Hourly Traffic Volume = 800

Travel Time = 5

Heavy Duty % = 10

Pollutant:	CO	PM2.5	PM10 <sup>10</sup>	NOx	VOC
NCHRP Output	1.8732	0.0417	0.0454	0.7250	0.1894
FHWA Output	1.873	0.056	0.180	0.725	0.189
Percent Difference	0.01%	25.54%	296.48%	0.00%	0.21%

Example 2: Interpolation performed

Inputs:

Year = 2021

Road Type = Urban

Corridor Length = 1

Number of Intersections = 6

Number of Lanes = 2

Speed Limit = 35

Signal Cycle Length = 90

Hourly Traffic Volume = 800

Travel Time = 5

Heavy Duty % = 10

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<sup>10</sup> PM values changed significantly for certain vehicle types between different MOVES versions. Because the two different tools were developed with different versions of MOVES, these comparisons will show differences in PM emissions outputs. Also, as noted previously, the errors in aggregation methodology for passenger vehicle emission rates result in the two outputs to differ drastically.

Pollutant:	CO	PM2.5	PM10 <sup>11</sup>	NOx	VOC
NCHRP Output	1.7326	0.0383	0.0417	0.6749	0.1730
FHWA Output	1.701	0.053	0.176	0.667	0.169
Percent Difference	1.86%	27.74%	322.06%	1.17%	2.31%

## INTERSECTION IMPROVEMENTS TOOL COMPARISON

### Intersection Improvements NCHRP Tool, Comparison of Results with CMAQ Tool

The examples below show a comparison of the NCHRP toolkit with the developed CMAQ Toolkit Intersection Improvements Tool. The NCHRP Intersection Tool uses the same MOVES run specification, as well as the same data aggregation post-processing scheme as the CMAQ tool.

#### Example 1: No Interpolation performed

Inputs:

Year = 2020

Area Type = Rural

Business District = No

Existing Signalization = Unsignalized

Truck Percentage = 10

Hourly Traffic Volume: Road 1 = 800; Road 2 = 800

Lanes: Road 1 = 2; Road 2 = 2

Delay: Road 1 = 35; Road 2 = 35

Existing Left-turn: No for both roads

Existing Right-turn: Yes for both roads

Left Turn Lanes to Add: Road 1 = 1; Road 2 = 0

Left-Turn Phase Added: Yes for both roads

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<sup>11</sup> PM values changed significantly for certain vehicle types between different MOVES versions. Because the two different tools were developed with different versions of MOVES, these comparisons will show differences in PM emissions outputs. Also, as noted previously, the errors in aggregation methodology for passenger vehicle emission rates result in the two outputs to differ drastically.

Right-Turn Phase Added: Yes for both roads

Signal Cycle Length = 90

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	1.4828	0.0864	0.0943	1.1368	0.2338
FHWA Output	1.483	0.086	0.094	1.135	0.234
Percent Difference	0.01%	0.47%	0.32%	0.16%	0.09%

Example 2: Interpolation performed

Inputs:

Year = 2021

Area Type = Rural

Business District = No

Existing Signalization = Unsignalized

Truck Percentage = 10

Hourly Traffic Volume: Road 1 = 800; Road 2 = 800

Lanes: Road 1 = 2; Road 2 = 2

Delay: Road 1 = 35; Road 2 = 35

Existing Left-turn: No for both roads

Existing Right-turn: Yes for both roads

Left Turn Lanes to Add: Road 1 = 1; Road 2 = 0

Left-Turn Phase Added: Yes for both roads

Right-Turn Phase Added: Yes for both roads

Signal Cycle Length = 90



Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	1.3191	0.0806	0.0879	1.0514	0.2110
FHWA Output	1.255	0.080	0.087	1.034	0.204
Percent Difference	5.11%	0.75%	1.02%	1.65%	3.32%

## ROUNABOUTS TOOL COMPARISON

The examples below show a comparison of the NCHRP toolkit with the developed CMAQ Toolkit Roundabouts Tool. The NCHRP Roundabouts Tool uses the same MOVES run specification, as well as the same data aggregation post-processing scheme as the FHWA tool.

### Example 1: No Interpolation performed

Inputs (for three approaches):

Year = 2020

Area Type = Rural

Business District = No

Truck Percentage = 10

Average Hourly Traffic Volume: Approaches 1-3 = 250

Lanes: Approaches 1-3 = 1

Existing Delay: App 1 = 55; App 2 = 30; App 3 = 45

Existing Left-turn %: Approaches 1-3 = 15%

Existing Right-turn %: Approaches 1-3 = 85%

Number of Circulating Roundabout Lanes = 1

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	1.5769	0.0927	0.1011	1.2279	0.2461
FHWA Output	1.577	0.093	0.101	1.226	0.246
Percent Difference	0.01%	0.32%	0.10%	0.15%	0.04%

Example 2: Interpolation performed

Inputs (for three approaches):

Year = 2021

Area Type = Rural

Business District = No

Truck Percentage = 10

Average Hourly Traffic Volume: Approaches 1-3 = 250

Lanes: Approaches 1-3 = 1

Existing Delay: App 1 = 55; App 2 = 30; App 3 = 45

Existing Left-turn %: Approaches 1-3 = 15%

Existing Right-turn %: Approaches 1-3 = 85%

Number of Circulating Roundabout Lanes = 1

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	1.4046	0.0865	0.0944	1.1376	0.2224
FHWA Output	1.338	0.086	0.094	1.119	0.215
Percent Difference	4.98%	0.58%	0.42%	1.64%	3.33%

## MANAGED LANES TOOL COMPARISON

Note that the CMAQ tool includes options for type of managed lane facility (i.e., continuous access, buffer, or barrier) to derive average speed estimates for the managed lanes and general purpose lanes. A correction factor is applied to the free flow speed (can be approximated as speed limit) to determine actual average speeds in the lanes, which are then used to determine emission benefits from traffic smoothing. The NCHRP tool assumes that the user already knows the average speed in the lanes.

### Example 1: No Interpolation performed

Inputs:

Year = 2020

Hours Operating Per Day = 4

Length of Facility = 5

Highway Type = Urban

Heavy Duty Fleet Mix = 40%

Traffic Flow Inputs:

- Average Hourly Flow: ML before = 0; GP before = 2500; ML after = 1000; GP after = 2500
- Average Hourly Speed: ML before = 0; GP before = 48; ML after = 61; GP after = 65
- Number of Lanes: ML before = 0; GP before = 3; ML after = 1; GP after = 3

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	263.7776	7.8900	8.5988	119.0135	12.9462
FHWA Output	272.8386	11.0572	22.5362	175.4551	14.8082
Percent Difference	3.32%	28.64%	162.09%	47.42%	14.38%

### Example 1: Interpolation performed

Inputs:

Year = 2021

Hours Operating Per Day = 4

Length of Facility = 5

Highway Type = Urban

Heavy Duty Fleet Mix = 40%

Traffic Flow Inputs:

- Average Hourly Flow: ML before = 0; GP before = 2500; ML after = 1000; GP after = 2500
- Average Hourly Speed: ML before = 0; GP before = 48; ML after = 61; GP after = 65
- Number of Lanes: ML before = 0; GP before = 3; ML after = 1; GP after = 3

Pollutant:	CO	PM2.5	PM10	NOx	VOC
NCHRP Output	245.7532	7.3267	7.9855	109.9173	11.7653
FHWA Output	249.8993	10.2586	21.6648	159.9687	13.1495
Percent Difference	1.66%	28.58%	171.30%	45.54%	11.77%