2023 Carbon Monoxide Categorical Hot-Spot Finding Technical Report

Federal Highway Administration

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1 Introduction

1.1 Purpose of this Document

This technical report describes the modeling analysis conducted to support the 2023 Federal Highway Administration (FHWA) carbon monoxide (CO) categorical hot-spot finding for intersections using MOVES3[1] and CAL3QHC.[2] The finding does not apply to California, which uses EMFAC[3] for its emissions model. The 2023 CO categorical finding replaces the single intersection of perpendicular highways modeled in the 2017 CO categorical finding with a skewed intersection modeled with four different scenarios of grade and truck percentages. These changes allow for wider application of the finding. Each scenario can be applied in a rural or urban area. This revised finding also modifies the acceptable ranges of modeling parameters based on FHWA's latest understanding of worst-case conditions. A comparison of the acceptable ranges of modeling parameters between the 2017 finding and the 2023 finding is found in Appendix A. Information on how to apply the finding as part of a project-level conformity determination is found in FHWA's CO categorical hot-spot finding, which is available on FHWA's *CO categorical hot-spot finding* website. Modeling files for MOVES3 and CAL3QHC are available via request from FHWA's Air Quality and Transportation Conformity Team at TAQC@dot.gov.

1.2 Regulatory Background for CO Categorical Hot-Spot Finding

A CO categorical hot-spot finding provision was added in the January 24, 2008 final conformity rule at 40 CFR 93.123(a)(3) and explained in the preamble at 73 FR 4432-4434. This provision allows the U.S. Department of Transportation (USDOT), in consultation with the Environmental Protection Agency (EPA) to make a categorical hot-spot finding that the requirements in 40 CFR 93.116(a) are met without any further hot-spot analysis for applicable FHWA and FTA projects in CO nonattainment or maintenance areas. This finding must be based on "appropriate modeling" and may consider current air quality circumstances for a given CO nonattainment or maintenance area. Note that in addition to conformity purposes, the CO categorical hot-spot finding can be applied for NEPA purposes as well to replace a microscale CO analysis. When applying the finding for NEPA purposes it may be necessary to apply the finding to several alternatives that are being compared in the NEPA document.

1.3 Overview of Modeling Approach

In order to meet the requirements in 40 CFR 93.123(a)(3), FHWA, in consultation with the EPA, conducted screening analyses for four scenarios of a large intersection

[1] MOVES 3.0.2 was used. See EPA's website at: https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves

[2] U.S. Environmental Protection Agency, *CAL3QHC, Version 2.0 with a date of 04244*, Technology Transfer Network, Support Center for Regulatory Atmospheric Modeling.

[3] California ARB, EMFAC2014 Volume I – User's Guide v.1.0.7, April 30th, 2014

operating at capacity using MOVES3 and CAL3QHC. The four scenarios represent different combinations of road grade and truck percentage, which FHWA found to be the most sensitive inputs. Table 1 defines the four scenarios of the 2023 CO categorical hot-spot finding that can be applied to projects. In comparison, the 2017 finding was for only one scenario, which was similar to the low-grade low truck percentage scenario found here. The additional scenarios allow for the wider application of the 2023 CO categorical hot-spot finding.

Table 1. 2023 Categorical Finding Scenarios

Scenario	Road Grade*	Truck Percentage**
High Grade High Truck Percentage	1% <upgrade≤ 6%	2% < trucks ≤ 20%
Low Grade High Truck Percentage	0% ≤ upgrade ≤ 1%	2% < trucks ≤ 20%
High Grade Low Truck Percentage	1% <upgrade≤ 6%	0% ≤ trucks ≤ 2%
Low Grade Low Truck Percentage	0% ≤ upgrade ≤ 1%	0% ≤ trucks ≤ 2%

*The highest grade from all upgrade roadway links at the project intersection should be used.
**The highest truck percentage (single unit and combination trucks) from all links at the project intersection should be used.

Modeling demonstrates that projects meeting the finding's parameters would not produce a CO concentration higher than what was modeled and, when combined with background concentrations within the parameters in Table 3 of the finding, would not violate the National Ambient Air Quality Standard (NAAQS) for CO. It is important to note that CO background concentration is a function of the location of a particular project and will need to be obtained by a project sponsor in a manner consistent with the 1992 CO Guideline[4] and the area's transportation conformity interagency consultation process.

The modeling analysis conducted for the categorical finding meets all the conformity requirements for a CO hot-spot analysis including 40 CFR 93.110, 93.111, 93.116(a), and 93.123(a) and (c) by using the latest versions of appropriate models; MOVES3 and CAL3QHC. In addition, the modeling analysis is consistent with EPA's guidance: "Guideline for Modeling Carbon Monoxide from Roadway Intersections"[4] (1992 CO Guideline) and "Using MOVES3 in Project-Level Carbon Monoxide Analyses"[5] (2021 CO MOVES3 Guidance).

[4]U.S. Environmental Protection Agency, Guideline for Modeling Carbon Monoxide from Roadway Intersections, EPA-454/R-92-005, Office of Air Quality Planning and Standards, November 1992. Found on EPA's website: https://www.epa.gov/state-and-local-transportation/project-level-conformity-and-hot-spot-analyses#coguidance.
[5] U.S. Environmental Protection Agency, Using MOVES3 in Project-Level Carbon Monoxide Analyses, EPA-420-B-21-047, Office of Transportation and Air Quality, December 2021.

1.4 Organization of Remainder of Document

Section 2 discusses the intersection design, Section 3 discusses the MOVES modeling, and Section 4 discusses the CAL3QHC modeling for each scenario. Appendix A compares this new 2023 finding to the previous 2017 finding.

2 Intersection Design

A large, signalized intersection is analyzed under both rural and urban conditions. An urban area has a population of 5,000 or greater within the FHWA adjusted urban area boundary.[6] All other areas are rural. Modeling the intersection under rural conditions is added to the previous 2017 categorical finding to expand the application of the finding to areas with populations less than 5000, for either transportation conformity or NEPA purposes.

The intersection has a 75-degree skew angle (see Figure 1). Based on the results of a previous FHWA sensitivity analysis[7], an intersection at a 75-degree angle represents the "worst-case" that is allowed by design standards[8]. The categorical finding can apply to intersections that are at any angle between 75 and 90 degrees. The orientation of the intersection is that the east leg and the north leg are 75 degrees apart from each other and that the west leg and the south leg are 75 degrees apart from each other. The configuration of the intersection represents an intersection on the side of hill. The westbound and northbound directions consist of the links with a positive grade (uphill) and eastbound and southbound directions consist of the links with a negative grade (downhill).

The intersection includes four approach lanes in each direction, four departure lanes in each direction, and two left turn lanes for each approach. The right lane in each direction is assumed to include both through and right turn movements. Lanes are 10 feet wide in all cases with no median width (median width = 0 feet). Based on the results of the previous sensitivity analysis[7], 10-foot lanes and no median width represent the "worst-case" when modeling for CO concentrations; for application purposes these should be considered the minimum widths. Figure 1 shows the diagram of the intersection that was modeled.

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[6] A map of FHWA Adjusted Urban Areas can be found at https://hepgis.fhwa.dot.gov/fhwagis/ViewMap.aspx?map=MPO+Boundaries|FHWA+Adjusted+Urban+Area. More information on the FHWA definition of urban area can be found at https://www.fhwa.dot.gov/planning%20/processes/statewide/related/highway_functional_classifications/section06.cfm

[7] The previous FHWA sensitivity analysis was based on MOVES2014, but the sensitivity of intersection design elements (skew angle, lane width, and median width) are based on CAL3QHC results not MOVES.

[8] American Association of State Highway and Transportation Officials (AASHTO). "The Green Book: A Policy on Geometric Design of Highways and Streets." 2018 (7th Edition), 2nd Printing. Section 9.4.2 of this design standard calls for a minimum angle of 75 degrees. The sensitivity analysis showed that pollutant concentrations increase as the intersection angle gets smaller; therefore, 75 degrees was chosen over 90 degrees as the worst-case angle.

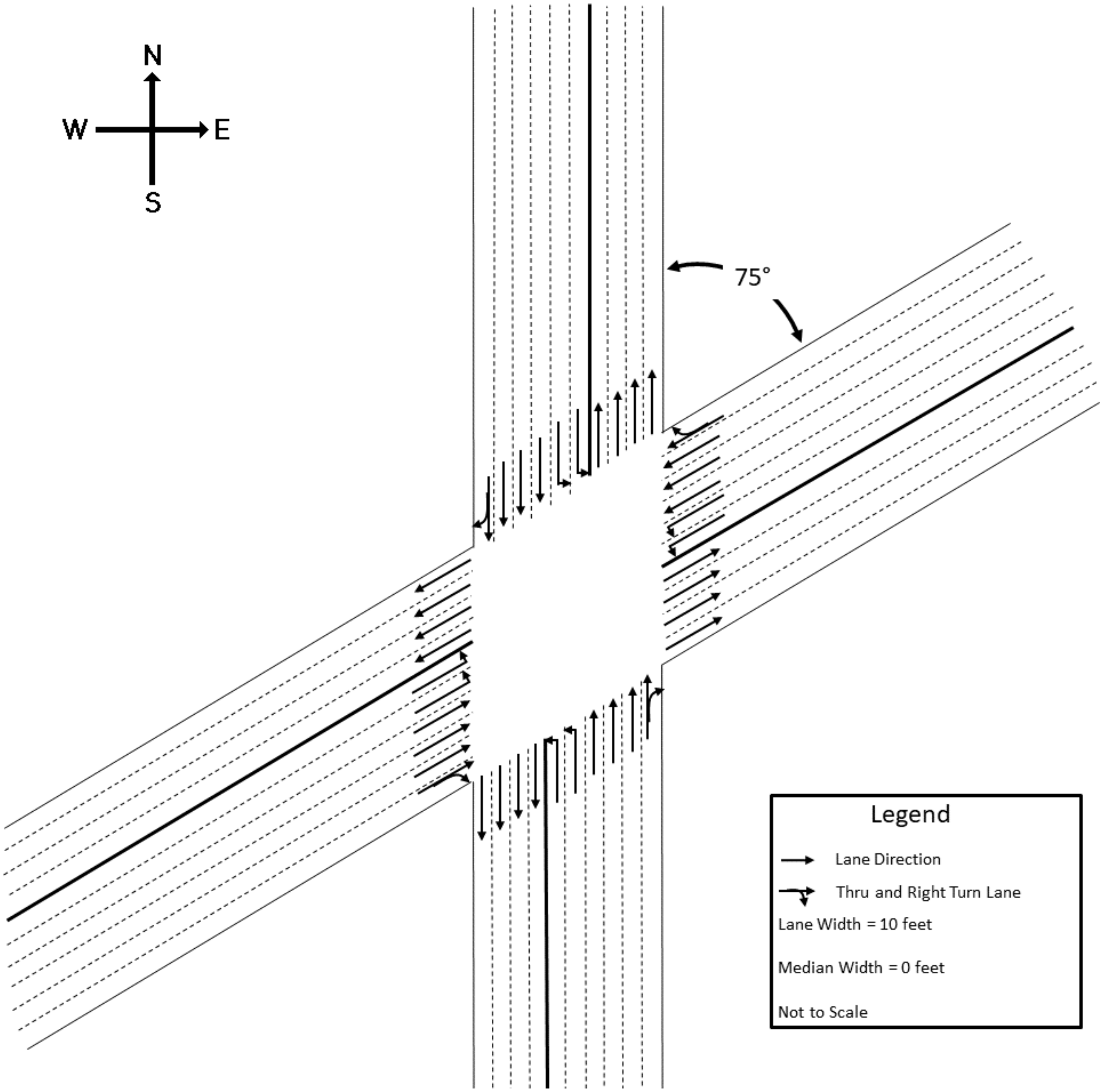

Figure 1. Modeled Intersection Diagram

2.1 Volume and Level of Service (LOS) Conditions

This intersection analysis utilizes the same volume and Level of Service (LOS) conditions that were used for FHWA's 2017 CO Categorical Hot-Spot Finding.[9] The 2017 CO Categorical Hot-Spot Finding analysis utilized 2010 Highway Capacity Manual Software[10] to calculate the approach volumes for a signalized intersection of LOS E (defined as an average control delay greater than 80 seconds per vehicle) and assumed that all approaches would have equal demand to represent a maximum total intersection throughput.

Consistent with FHWA's 2017 CO Categorical Hot-Spot Finding, this intersection analysis utilized a flow rate of 2640 vehicles per hour for each approach leg while maintaining LOS E conditions. Of those 2640 vehicles, 396 vehicles (15%) were assigned to the left-turn lanes and the remaining 2244 vehicles were assigned to the through lanes, including the shared through-right turn lane.

2.2 Signal Timing

Directly related to the volume of an intersection is the signal timing. Consistent with the 2017 finding, which was based on the HCM2010 software, the signal times were determined to be 130 seconds for the total cycle (red to red for one direction), an average green time of 41 seconds for the through and right turn movements occurring at the same time for opposing approaches, and 14 seconds for the average left turn movement concurrent in opposing directions.

2.3 Grade and Speed

The 1992 CO Guideline[4] recommends using a congested free-flow speed, which would typically be less than the posted speed. It suggests that this speed could range from 15 to 45 miles per hour (mph) for arterial roadways with a signalized intersection. A separate analysis with MOVES3 modeled speeds in 1 mph increments in this range and found 15 mph to yield the worst-case CO concentrations. The intersection analysis for this finding uses this worst-case 15 mph as the approach and departure speeds for all links. Application of the finding is restricted to speeds in the range of 15 to 45 mph to correspond to the 1992 CO Guideline[4] and because sensitivity analysis with speed and road grade combined show an increase in emission rates above 45 mph (i.e., emissions greater than produced at a speed of 15 mph). The link level average speeds are further discussed in section 3.2.

Two sets of grades were modeled for the intersection analysis. Grades of ±1% and ±6% were modeled. As discussed previously in Section 1, the ±1% grades were modeled for the low-grade scenarios (Low Grade High Truck and Low Grade Low Truck scenarios)

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[9] Federal Highway Administration, Carbon Monoxide Categorical Hot-Spot Finding Technical Report, June 2017, https://www.fhwa.dot.gov/environment/air_quality/conformity/policy_and_guidance/cmcf_2017/technical_document.pdf

[10] *Highway Capacity Manual*, Transportation Research Board, Washington, D.C., 2010.

and the ±6% grades were modeled for the high-grade scenarios (High Grade High Truck and High Grade Low Truck scenarios). Table 2 lists the final geometric and traffic parameters used in the modeling.

Table 2. Final Geometric and Traffic Characteristics for the Intersection

Component	Description
Lane configuration	• 4 through lanes and 2 left turn lanes per approach and 4 departure lanes per each leg of the intersection • 75-degree skew angle
Lane width	10 feet
Signalization	• Cycle length of 130 seconds with average green time length of 14 seconds for the left turn and average green time length for the right/through traffic of 41 seconds • Average intersection control delay is 78.5 seconds per vehicle during the peak hour
Turning movements	15% left turn and 5% right turn
Median width	None
Traffic volume	• 2640 vehicles per hour on each approach during the peak hour • On each approach: 2244 are through traffic or turning right; remaining 396 vehicles turn left to characterize vehicle queuing
Level of service	E
Grade	+/- 1% and +/- 6%
Heavy-duty trucks	2% trucks and 20% trucks
Peak hour average approach speed	15 mph

3 MOVES Modeling

MOVES3[1] was used to model CO emissions for this analysis. Each MOVES input parameter is discussed in this section and is consistent with the 2021 CO MOVES3 Guidance.[5]

3.1 Run Specification (RunSpec) Inputs

The MOVES inputs described in this section were used to model the all the intersection scenarios.

3.1.1 Scale

This intersection analysis is a project-level analysis using the project domain and Inventory calculation type. The Inventory calculation type provides the required information needed to calculate idle and free-flow emission rates for input into CAL3QHC (see Section 3.3).

3.1.2 Time Spans

- Year - 2022

2022 was chosen for the year of analysis because CO emission rates decline steadily in future years and 2022 represents the year in which the highest CO emission rates will occur and the first year this modeling will be used. Any year after 2022 would yield lower CO emission rates and lower modeled CO concentration levels[11].

- Month – January

Following the 1992 CO Guideline[4] and the 2021 CO MOVES3 Guidance[5], the month of January was selected. Refer to the Meteorology Data discussion within the Project Data Manager sub-section for more details.

- Day – Weekday

MOVES requires either a weekday or weekend to be chosen for project-level modeling. Since either choice would not impact modeling results, the analysis was conducted for a weekday.

- Hour - 08:00 to 08:59 a.m.

[11] Volpe National Transportation Systems Center. MOVES2010a Regional Level Sensitivity Analysis. Figure D-19 and Table D-43 through Table D-45. Available: https://rosap.ntl.bts.gov/view/dot/9706

MOVES requires a specific hour to be chosen for project-level modeling; 8:00- 8:59 am was selected to represent peak hour data for the intersection.

3.1.3 Geographic Bounds

The 2017 finding used the Custom Domain option under Geographic Bounds; however, since MOVES3 removed that option, Washtenaw County, MI was used as the county for this analysis. This selection was inconsequential since the CO emission rates are driven by the other MOVES inputs described in this section.

3.1.4 Vehicles/Equipment

All 13 MOVES source use types and valid fuel combinations were selected for this analysis. Table 3 lists the vehicle and fuel type combinations utilized in this analysis. Please refer to the Fuel discussion (Section 3.2.3) within the Project Data Manager sub-section for more information on fuel type adjustments to the source type and fuel type combinations for this analysis.

Table 3. Vehicles and Equipment Fuel Combinations

Source Use Types	Fuel Type(s)
Motorcycle	Gasoline
Passenger Car	Diesel Fuel, Gasoline, Electricity, and Ethanol (E-85)*
Passenger Truck	Diesel Fuel, Gasoline, Electricity, and Ethanol (E-85)*
Light Commercial Truck	Diesel Fuel, Gasoline, Electricity, and Ethanol (E-85)*
Refuse Truck	Diesel Fuel, Gasoline, and CNG
Motor Home	Diesel Fuel, Gasoline, and CNG
School Bus	Diesel Fuel, Gasoline, and CNG
Transit Bus	Diesel Fuel, Gasoline, and CNG
Other Buses	Diesel Fuel, Gasoline, and CNG
Single Unit Short-haul Truck	Diesel Fuel, Gasoline, and CNG
Single Unit Long-haul Truck	Diesel Fuel, Gasoline, and CNG
Combination Short-haul Truck	Diesel Fuel, Gasoline, and CNG
Combination Long-haul Truck	Diesel Fuel

*E-85 is included here to account for Vehicle Miles Traveled (VMT) only. No E-85 is used for this analysis. Please refer to section 3.2.3 to the discussion on fuel usage fraction for more information.

3.1.5 Road Type

The Urban Unrestricted and Rural Unrestricted road types were used to represent urban and rural intersection links, respectively.

3.1.6 Pollutants and Processes

The intersection scenario required the Running Exhaust and Crankcase Running Exhaust emissions processes for CO to be selected.

3.1.7 Output

Table 4 lists the General Output selections and Table 5 lists the Output emissions detail selections used for this analysis.

Table 4. General Output Selections

Heading	Selection(s)
Units	Mass Units = Grams
	Energy Units = Joules
	Distance Units = Miles
Activity	Distance Traveled
	Source Hours Operating
	Population

Table 5. Output Emissions Detail

Heading	Selection(s)
Output Aggregation	Time: Hour
	Geographic: LINK
For all Vehicle/Equipment Categories	No Selections
On Road	No Selections
Off Road	No Selections

3.2 Project Data Manager

3.2.1 Meteorology Data

Following the 1992 CO Guideline[4] and the 2021 CO MOVES3 Guidance[5], the analysis utilized an average January temperature and humidity. A previous sensitivity analysis[12] found the worst-case CO running emission rates at 90° Fahrenheit and above due to

[12] The previous sensitivity analysis used MOVES2014, but the temperature and air conditioning adjustments for running CO emissions in MOVES2014 and MOVES3 are the same. See “Emission Adjustments for Temperature, Humidity, Air Conditioning and Inspection and Maintenance for Onroad Vehicles in MOVES3” at https://www.epa.gov/system/files/documents/2022-07/420r22016.pdf and “Emission Adjustments for Temperature, Humidity, Air Conditioning, and Inspection and Maintenance for On-road Vehicles in MOVES2014” at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NOEM.pdf.

the air conditioning usage. However, an analysis by FHWA of the MOVES3 default database found that the highest average January temperature in the continental United States is 66.55°F for Monroe County, FL, which was rounded up to 70° Fahrenheit for use in this analysis. “Relative humidity” was set at 100%. Due to air conditioning usage, these values result in higher CO emission rates than an area with a lower average January temperature and a lower relative humidity.

3.2.2 Age Distribution

The 2021 CO MOVES3 Guidance[5] allows for default age distribution from MOVES to be used when no other state or local data is available. Because this analysis is not focused on a specific area, the MOVES3 national default age distribution representing the 2022 analysis year was used.

3.2.3 Fuel

The 2021 CO MOVES3 Guidance[5] recommends that the default MOVES fuel supply and fuel formulation data be utilized representing the project specific area. However, for the intersection analysis a fuel type with specific parameters that would yield the highest CO emission rates for 2022 was used to have widest applicability.

- Fuel Supply Data

  In order to determine which gasoline fuel formulation would produce the highest CO emission rates, a separate analysis was conducted, which was similar to the one done for the 2017 CO Categorical Finding[9]. This analysis modeled the default January 2022 fuel supply from all 22 fuel regions that appear in the MOVES3 default database for that year using Denver County, Colorado as a generic county for conducting the MOVES runs. The CO emission rates were compared from these 22 fuel regions and fuel region ID 700000000 (all Alaska counties), which has one of the highest Reid Vapor Pressure (RVP) values in the nation, was determined to produce the highest CO emission rates. Therefore, the fuel supply from this fuel region as shown in Table 6 is utilized for this analysis.

Table 6. Fuel Supply Input

fuelRegionID	fuelYearID	monthGroupID	fuelFormulationID	marketShare	marketShareCV
700000000	2022	1	90	1	0.5
700000000	2022	1	2931	1	0.5
700000000	2022	1	25003	1	0.5
700000000	2022	1	27001	1	0.5
700000000	2022	1	28001	1	0.5

- Fuel Formulation Data

  Fuel formulation parameters can significantly affect the CO emission rates. Gasoline Fuel parameters that can affect CO emission rates include Reid Vapor Pressure (RVP), Sulfur Content, Ethanol (ETOH), and E200/E300 (percent of fuel evaporated at 200° and 300° Fahrenheit). Table 7 lists the key fuel formulation parameters used for this analysis.

Table 7. Fuel Formulation Parameters

Fuel Type	fuelFormulationID	RVP	Sulfur Content (ppm)	ETOHVolume	e200	e300	T50	T90
Electricity	90	0	0	0	0	0	0	0
Gasoline	2931	14.5	6	0	56.721	96.334	186.1	268.8
Diesel	25003	0	6	0	0	0	0	0
Ethanol (E-85)	27001	10.5	8	74	999	999	999	999
CNG	28001	0	7.6	0	0	0	0	0

- Fuel Usage Fraction

  The Fuel Usage Fraction applies an adjustment for E-85 usage among gasoline vehicles that are E-85 capable. Due to the CO emission rates for source types that utilize E-85 being lower compared to the CO emission rates of those source type that utilize gasoline, analysis assumes no E-85 utilization for E-85 capable vehicles to be conservative. This will result in higher CO emission rates than if E-85 was included in the analysis.

- AVFT Data source

  As a conservative assumption, adjustments were made to Single-Unit Short Haul Trucks (Source Type 52) and Single-Unit Long Haul Trucks (Source Type 53) to reflect that these source types utilize 100% gasoline fuel and 0% diesel. All other source types utilize the MOVES3 default 2022 AVFT distributions.

3.2.4 Inspection and Maintenance (I/M) Programs

No I/M program was modeled in the analysis due to the variation in I/M programs across the CO maintenance areas. Also, including an I/M program would yield lower CO emission rates.

3.2.5 Links

The intersection scenario was modeled using Urban Unrestricted and Rural Unrestricted road types. As previously discussed, there are four scenarios that were modeled for the intersection analysis. Twenty-four unique links were modeled and their characteristics and definitions are listed in Table 8.

CO emission rates in grams per vehicle mile (grams/veh-mile) were obtained for each link with exception of the idle link where CO emission rates are in grams-per–vehicle-hour (grams/veh-hour). During emission modeling, each link length was set to a 1 mile segment with a volume of 1000 vehicles per hour to allow ease in extracting the appropriate data. This is different from the dispersion links that will be described later in this report.

Table 8. Links Characteristics

Scenario	linkId	Road Type	Link Length (mile)	Volume	Average Speed (mph)	Grade (%)	Link Definition
High Grade High Truck	1	Urban Unrestricted	1	1000	0	6%	Queue (idle)
	2	Urban Unrestricted	1	1000	15	6%	Free flow (approach/departure)
	3	Urban Unrestricted	1	1000	15	-6%	Free flow (approach/departure)
	4	Rural Unrestricted	1	1000	0	6%	Queue (idle)
	5	Rural Unrestricted	1	1000	15	6%	Free flow (approach/departure)
	6	Rural Unrestricted	1	1000	15	-6%	Free flow (approach/departure)
Low Grade High Truck	7	Urban Unrestricted	1	1000	0	1%	Queue (idle)
	8	Urban Unrestricted	1	1000	15	1%	Free flow (approach/departure)
	9	Urban Unrestricted	1	1000	15	-1%	Free flow (approach/departure)
	10	Rural Unrestricted	1	1000	0	1%	Queue (idle)
	11	Rural Unrestricted	1	1000	15	1%	Free flow (approach/departure)
	12	Rural Unrestricted	1	1000	15	-1%	Free flow (approach/departure)
High Grade Low Truck	13	Urban Unrestricted	1	1000	0	6%	Queue (idle)
	14	Urban Unrestricted	1	1000	15	6%	Free flow (approach/departure)
	15	Urban Unrestricted	1	1000	15	-6%	Free flow (approach/departure)
	16	Rural Unrestricted	1	1000	0	6%	Queue (idle)
	17	Rural Unrestricted	1	1000	15	6%	Free flow (approach/departure)
	18	Rural Unrestricted	1	1000	15	-6%	Free flow (approach/departure)
Low Grade Low Truck	19	Urban Unrestricted	1	1000	0	1%	Queue (idle)
	20	Urban Unrestricted	1	1000	15	1%	Free flow (approach/departure)
	21	Urban Unrestricted	1	1000	15	-1%	Free flow (approach/departure)
	22	Rural Unrestricted	1	1000	0	1%	Queue (idle)
	23	Rural Unrestricted	1	1000	15	1%	Free flow (approach/departure)
	24	Rural Unrestricted	1	1000	15	-1%	Free flow (approach/departure)

3.2.6 Link Source Types

The fractions of the link traffic volume for each MOVES source type were based on the source hours operating (SHO) output from a MOVES3 national scale run for the year 2022 for Urban Unrestricted and Rural Unrestricted road types. The Source Type Hour Fraction from this output was adjusted as described below to reflect:

1. the two truck scenarios (2% and 20% heavy-duty trucks), and
2. as a conservative assumption, a higher proportion of vehicles that have higher CO emission rates.

These are explained further below:

- **Heavy Duty Truck Adjustment**: MOVES3 defaults for the link source type input were modified to reflect the low truck and high truck scenarios described above. First, default link source type distributions for both rural unrestricted access (road type 3) and urban unrestricted access (road type 5) were calculated from the source hours operating (SHO) activity output from a MOVES3 default scale January 2022 weekday run. For the low truck scenario 2% was distributed among source types 52, 53, 61, and 62 using MOVES default distributions for each of the two road types. Similarly, for the high truck scenario 20% was distributed among source types 52, 53, 61, and 62 using MOVES default distributions for each of the two road types.

- **Passenger Vehicles Adjustment**: The fraction of passenger vehicles is adjusted up for the 2% heavy-duty truck scenario and down for the 20% heavy-duty truck scenario to ensure that the fractions of all source types sum to 100%. The fraction of passenger vehicles (source type 21 and 31) is found by subtracting the percentage of vehicles that are trucks (i.e., either 2% or 20%) and the percentages of remaining source types (11, 32, 41, 42, 43, 51, and 54) from 100%. This passenger vehicle percentage is then split into 70% passenger trucks (source type 31) and 30% passenger cars (source type 21) as a conservative assumption.

Table 9 lists the Link Source Type distributions utilized for the intersection analysis and includes all the adjustments described above.

Table 9. Urban and Rural Link Source Type Distributions for 5% and 20% Truck Percentage Scenarios

SourceTypeID	Description	Urban Unrestricted 2% Trucks	Rural Unrestricted 2% Trucks	Urban Unrestricted 20% Trucks	Rural Unrestricted 20% Trucks
11	Motorcycle	0.002455	0.002505	0.002455	0.002505
21	Passenger Car	0.2735	0.2751	0.2195	0.2211
31	Passenger Truck	0.6381	0.6419	0.5121	0.5159
32	Light Commercial Truck	0.05932	0.05223	0.05932	0.05223
41	Intercity Bus	0.002992	0.003259	0.002992	0.003259
42	Transit Bus	0.000985	0.001048	0.000985	0.001048
43	School Bus	0.001388	0.001907	0.001388	0.001907
51	Refuse Truck	0.0002829	0.0004134	0.0002829	0.0004134
52	Single Unit Short-haul Truck	0.01081	0.008029	0.1081	0.08029
53	Single Unit Long-haul Truck	0.0006605	0.0005098	0.006605	0.005098
54	Motor Home	0.001075	0.001637	0.001075	0.001637
61	Combination Short-haul Truck	0.002442	0.00296	0.02442	0.02960
62	Combination Long-haul Truck	0.006086	0.008502	0.06086	0.08502
All sources	Total	1.000	1.000	1.000	1.000

3.2.7 Link Drive Schedule

User-defined Link Drive Schedules were not utilized for this analysis.

3.2.8 Operating Mode Distribution

User-defined Operating Mode Distributions were not utilized for this analysis.

3.2.9 Off-Network

Off-Network links were not included in this analysis.

3.2.10 Advanced Performance Features

No Advanced Performance Features were utilized for the analysis

3.3 MOVES Output

This analysis utilized the inventory approach in obtaining MOVES output consistent with the 2021 CO MOVES3 Guidance[5]. The CO emission rates in grams per vehicle-mile were calculated for approach/departure links by dividing the total emissions (grams) by the 1000 vehicle-miles input for each link. The CO emission rates in grams per vehicle-hour were calculated for queue links by dividing the total emissions (grams) by the 1000 vehicle-hours for each link. Table 10 lists the emissions rates for the links associated with each scenario and used with CAL3QHC for air quality dispersion modeling.

Table 10. MOVES Link Based Emission Rates

Scenario	linkId	Road Type	Average Speed (mph)	Grade (%)	Emission Rate	Emission Rate Unit	Link Definition
High Grade High Truck Percentage	1	Urban Unrestricted	0	6%	15.4764	g/veh-hr	Queue (idle)
	2	Urban Unrestricted	15	6%	18.7974	g/veh-mile	Free flow (approach/departure)
	3	Urban Unrestricted	15	-6%	4.97815	g/veh-mile	Free flow (approach/departure)
	4	Rural Unrestricted	0	6%	14.7981	g/veh-hr	Queue (idle)
	5	Rural Unrestricted	15	6%	17.5917	g/veh-mile	Free flow (approach/departure)
	6	Rural Unrestricted	15	-6%	4.75951	g/veh-mile	Free flow (approach/departure)
Low Grade High Truck Percentage	7	Urban Unrestricted	0	1%	15.4764	g/veh-hr	Queue (idle)
	8	Urban Unrestricted	15	1%	10.5371	g/veh-mile	Free flow (approach/departure)
	9	Urban Unrestricted	15	-1%	8.547	g/veh-mile	Free flow (approach/departure)
	10	Rural Unrestricted	0	1%	14.7981	g/veh-hr	Queue (idle)
	11	Rural Unrestricted	15	1%	9.92674	g/veh-mile	Free flow (approach/departure)
	12	Rural Unrestricted	15	-1%	8.0949	g/veh-mile	Free flow (approach/departure)
High Grade Low Truck Percentage	13	Urban Unrestricted	0	6%	10.766	g/veh-hr	Queue (idle)
	14	Urban Unrestricted	15	6%	15.1181	g/veh-mile	Free flow (approach/departure)
	15	Urban Unrestricted	15	-6%	4.39289	g/veh-mile	Free flow (approach/departure)
	16	Rural Unrestricted	0	6%	10.7244	g/veh-hr	Queue (idle)
	17	Rural Unrestricted	15	6%	15.0203	g/veh-mile	Free flow (approach/departure)
	18	Rural Unrestricted	15	-6%	4.37381	g/veh-mile	Free flow (approach/departure)
Low Grade Low Truck Percentage	19	Urban Unrestricted	0	1%	10.766	g/veh-hr	Queue (idle)
	20	Urban Unrestricted	15	1%	8.62989	g/veh-mile	Free flow (approach/departure)
	21	Urban Unrestricted	15	-1%	7.25316	g/veh-mile	Free flow (approach/departure)
	22	Rural Unrestricted	0	1%	10.7244	g/veh-hr	Queue (idle)
	23	Rural Unrestricted	15	1%	8.5807	g/veh-mile	Free flow (approach/departure)
	24	Rural Unrestricted	15	-1%	7.21593	g/veh-mile	Free flow (approach/departure)

4 CAL3QHC Modeling

Dispersion modeling was completed using the recommended CAL3QHC model, Version 2.0[2] and as prescribed for CO screening analyses of highway-only projects by the 1992 CO Guideline[4]. In total, there were 8 individual CAL3QHC modeling runs conducted representing urban and rural conditions for the four scenarios. Table 11 lists the CAL3QHC modeling runs that were conducted.

Table 11. CAL3QHC Modeling Runs

Run Number	Scenario	Urban or Rural Conditions
1	High Grade High Truck	Urban
2	High Grade High Truck	Rural
3	Low Grade High Truck	Urban
4	Low Grade High Truck	Rural
5	High Grade Low Truck	Urban
6	High Grade Low Truck	Rural
7	Low Grade Low Truck	Urban
8	Low Grade Low Truck	Rural

The following discussion describes the CAL3QHC inputs used for the intersection analysis.

4.1 Intersection Inputs

4.1.1 Intersection Legs

Dispersion links were extended out to 3000 feet (914 meters) from the intersection so that midblock receptor locations at 1500 feet (457 meters) from the intersection could be evaluated without end effects occurring.

4.1.2 Receptors

Receptors were placed according to the 1992 CO Guideline[4] at no closer than 10 feet (3 meters) to the roadway edge to account for the mixing zone and extending away from the intersection out to midblock. The example receptor locations as described in the

1992 CO Guideline[4] are shown in Figure 2.

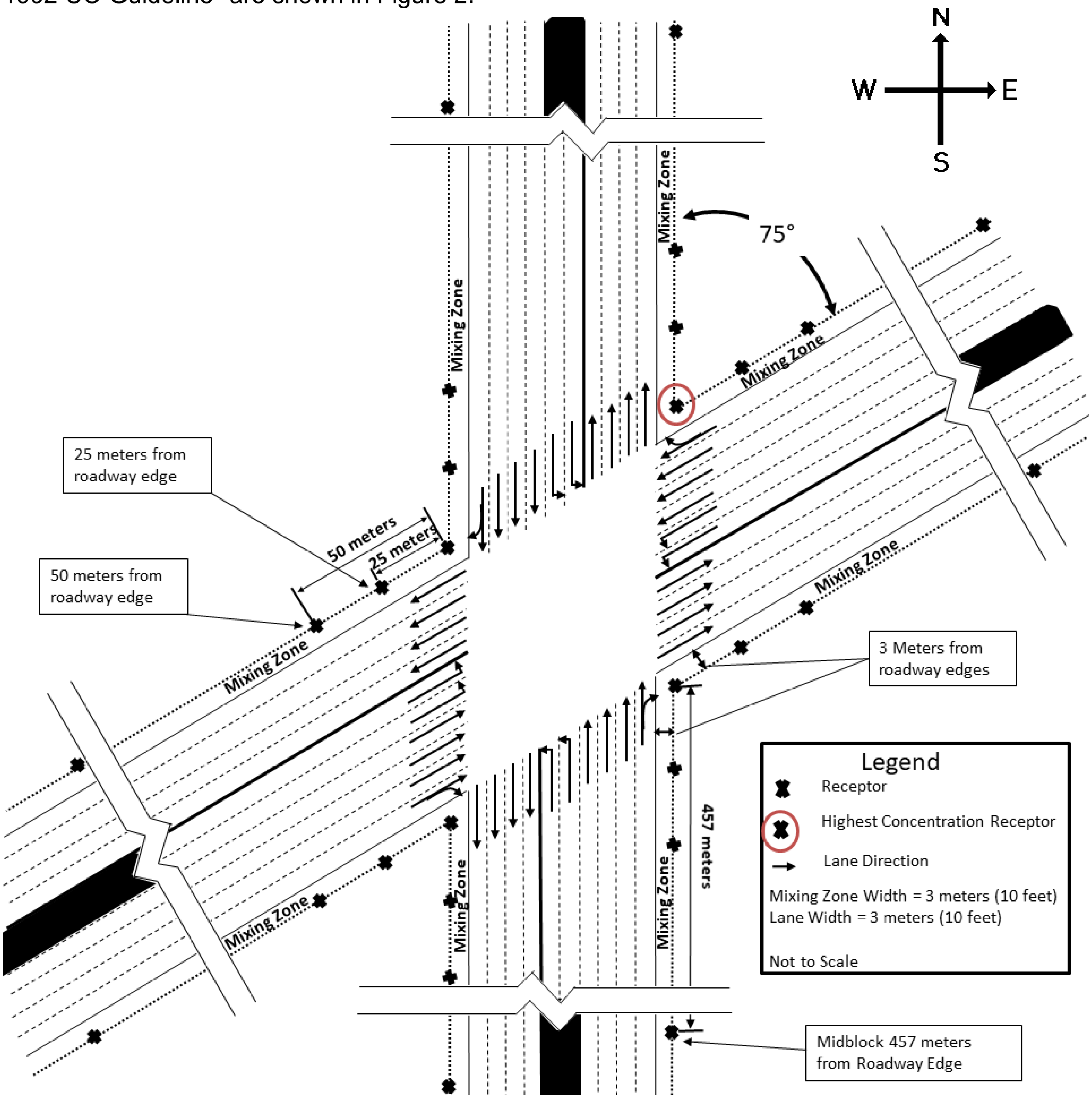

Figure 3 displays all receptor locations, the layout that was modeled, and the location of the receptor with the highest concentration.

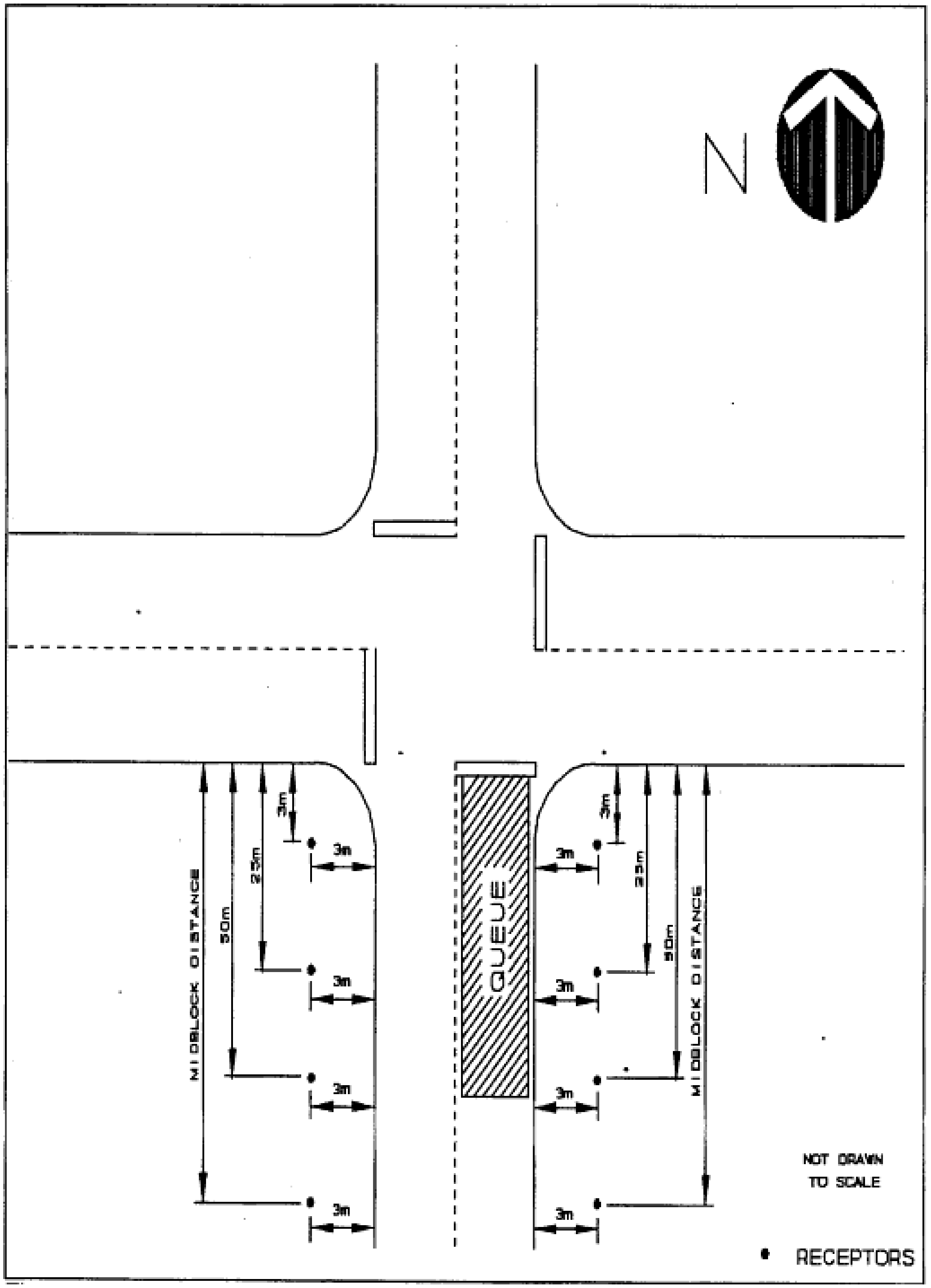

Figure 2. Receptor Locations as Defined by the 1992 CO Guideline[4]

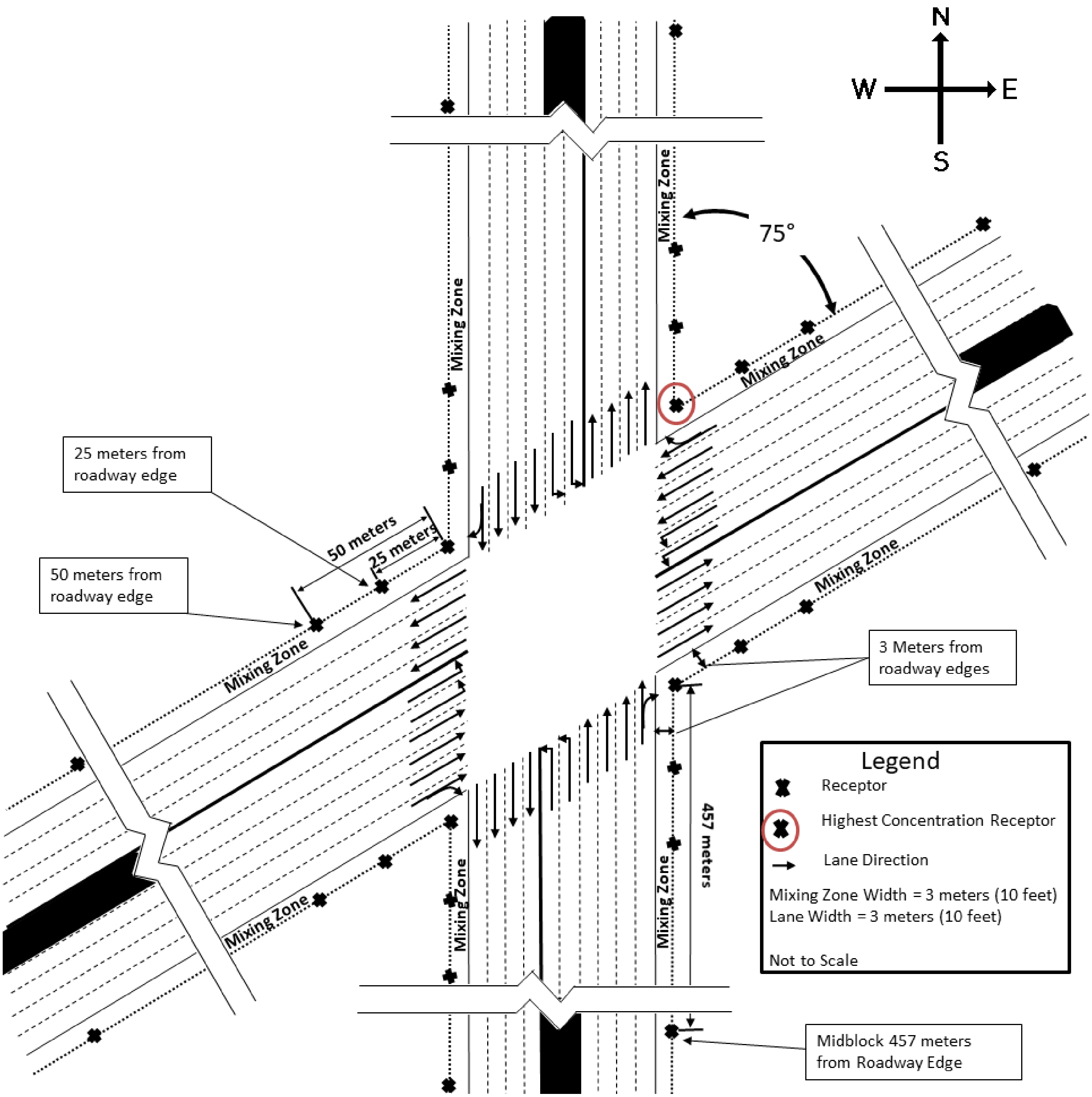

Figure 3. Intersection Receptor Locations and Layout

4.1.3 Meteorology

- Wind Speed and Direction

  The worst-case surface meteorology that follows the 1992 CO Guideline[4] was used. Wind speed was assumed to be 1.0 meters-per-second to ensure worst-case modeled CO concentration levels. The wind direction was evaluated every 10 degrees from 0 to 360 degrees so the maximum CO concentration would be obtained for the full range of possible wind directions.

- Stability and Mixing Height

  Consistent with the 1992 CO Guideline[4], an urban worst case stability class of D was modeled for the urban intersection scenarios and the rural worst-case stability class of E was modeled for the rural intersection scenarios. A mixing height of 1000 meters was modeled for both urban and rural intersection scenarios.

4.1.4 Surface Roughness

Consistent with the 1992 CO Guideline[4], a surface roughness of 108 centimeters, corresponding to a single family residential condition was modeled for urban intersection scenarios. For rural intersection scenarios, a surface roughness of 0.03 centimeters corresponding to a smooth desert condition was modeled.

4.1.5 Summary of CAL3QHC Inputs

Table 12 summarizes the final CAL3QHC input parameters used for modeling the intersection. Emission rates will vary for each scenario. Stability class and surface roughness will vary for urban and rural conditions. All other input parameters listed in Table 12 are the same across all CAL3QHC runs and the intersection leg specific parameters are the same across all intersection legs for each CAL3QHC run.

Table 12. Summary of CAL3QHC Inputs Used for the Intersection Modeling

CAL3QHC Input Parameter	Value or Description
Intersection Design and Receptor Locations	Please refer to Figure 3.
Meteorology	Wind speed = 1 m/s
	Wind direction = every 10 degrees from 0 to 350 degrees
	Mixing height = 1000 meters
	Stability class = D (urban) and E (rural)
	Surface roughness = 108 cm (Urban) and 0.03 cm (Rural)
Emission Factors	Please refer to Table 10 for scenario-specific emission rates
Number of Through Lanes	4
Number of Left-turn Lanes	2
Total Approach Volume – Free flow link (vph)	2640
Left-turn Traffic Volume – Queue link (vph)	396
Through Traffic Volume – Queue link (vph)	2244
Departure Traffic Volume – Free flow link (vph)	2640
Width per Lane (meters)	3.048
Right-of-Way Distance from Road Edge (meters)	3
Approach Segment Length (meters)	914.4
Approach Segment Median Width (meters)	0
Approach Segment Alignment N/S (deg)	0
Average Total Cycle Length (s)	130
Average Red Cycle Length - Thru (s)	91
Average Red Cycle Length - Left (s)	118
Clearance Lost Time (s)	2
Saturation Flow Rate (vphpl)	1600
Signal Type	Pretimed
Arrival Rate	Average
Output from CAL3QHC	Parts-per-million for 1-hour concentration

4.2 CAL3QHC Output

1-hour CO concentrations were modeled using CAL3QHC at the selected receptor locations. Table 13 shows the 1-hour CO concentration modeling results for the eight CAL3QHC runs (urban and rural conditions for four scenarios).

Table 13. CO Concentration Modeling Results by Scenario and Urban/Rural

Intersection Scenario	Urban/Rural	1 Hour CO Concentration Modeling Results (PPM)
High Grade High Truck	Urban	5.2
	Rural	7.3
Low Grade High Truck	Urban	3.7
	Rural	5.4
High Grade Low Truck	Urban	4.2
	Rural	6.1
Low Grade Low Truck	Urban	3
	Rural	4.7

5 Background Concentration Values

No background concentration values were included in the modeling since this will be a function of the project location and will be determined on a project-specific basis using the appropriate methodology such as described in the 1992 CO Guideline.[4]

6 Persistence Factor

The CO NAAQS consists of both 1-hour and 8-hour standards. To allow comparison to both the 1-hour and the 8-hour NAAQS for CO, the 1992 CO Guideline[4] recommends using a persistence factor to convert peak 1-hour modeled concentrations to peak 8-hour estimations. Use of this persistence factor allows for the changes in traffic volumes and meteorological conditions over the 8-hour period as compared to the 1-hour period. If a local persistence factor based on monitoring data is unavailable, the 1992 CO Guideline[4] recommends using a default persistence factor of 0.7.

For the intersection analysis, the 1-hour concentration was first modeled using CAL3QHC. Then, using the procedure described above, the predicted 1-hour concentration was multiplied by the persistence factor to allow for the estimation of the 8-hour concentration. The persistence factors used differ depending on the method chosen for the application of the CO categorical hot-spot finding:

1) For the tables in the Appendix of the finding, the modeled 1-hour concentration was multiplied by two default persistence factors:
    a. 0.7 as a worst-case persistence factor to represent values between 0-0.7, and
    b. 1.0 as a worst-case persistence factor to represent values between 0.7-1.0.

2) For the spreadsheet tool, the modeled 1-hour concentration is multiplied by:
    a. 0.7 as a default persistence factor to represent values between 0-0.7, and
    b. The exact persistence factor entered for values between 0.7-1.0.

7 Results

The MOVES results are presented in Section 3.3 as emission factors with units of grams per vehicle-mile, while the CAL3QHC results are presented in Section 4.2 as 1-hour CO concentrations with units of parts per million (PPM). The 1-hour CO concentrations are converted to 8-hour CO concentration estimates by multiplying by the persistence factors described in Section 6. The allowable background concentrations are calculated by subtracting the concentration results from the applicable National Ambient Air Quality Standard (NAAQS). For example, the allowable 1-hour CO background is calculated by subtracting the 1-hour CO concentration modeling results from the 1-hour NAAQS of 35 ppm. The allowable 8-hour background concentration is calculated by subtracting the 8-hour concentration estimate from the 8-hour NAAQS of 9 ppm. Table 14 shows the results of these calculations, which include the 1-hour and 8-hour concentrations and 1-hour and 8-hour allowable background concentrations. These results are presented for the four scenarios described in Table 1, urban/rural designations, and persistence factors of 0.7 and 1.0. These are the results used to define the acceptable ranges that vary by scenario for the 2023 categorical hot-spot finding (Table 4 in the Appendix of the 2023 Categorical Hot-spot Finding Document).

Table 14. 2023 Categorical Finding Allowable CO Background Concentrations

Intersection Scenario	Urban/ Rural	1 Hour CO Concentration Modeling Results (PPM)	Allowable 1-Hour CO Background (PPM)*	8 Hour CO Concentration Estimates (PPM) – 0.7 Persistence Factor	Allowable 8 Hour CO Background (PPM)** – 0.7 Persistence Factor	8 Hour CO Concentration Estimates (PPM) – 1.0 Persistence Factor	Allowable 8 Hour CO Background (PPM)** – 1.0 Persistence Factor
High Grade High Truck	Urban	5.2	29.8	3.64	5.36	5.2	3.80
	Rural	7.3	27.7	5.11	3.89	7.3	1.70
Low Grade High Truck	Urban	3.7	31.3	2.59	6.41	3.7	5.30
	Rural	5.4	29.6	3.78	5.22	5.4	3.60
High Grade Low Truck	Urban	4.2	30.8	2.94	6.06	4.2	4.80
	Rural	6.1	28.9	4.27	4.73	6.1	2.90
Low Grade Low Truck	Urban	3	32	2.1	6.9	3	6.00
	Rural	4.7	30.3	3.29	5.71	4.7	4.30

* Allowable 1 Hour CO Concentration Background calculated by subtracting the 1 Hour CO Concentration from the 1 Hour National Ambient Air Quality Standards (35 ppm)
** Allowable 8 Hour CO Concentration Background calculated by subtracting the 8 Hour CO Concentration from the 8 Hour National Ambient Air Quality Standards (9 ppm)

Appendix A : Comparison of 2017 Finding to 2023 Finding

The 2023 CO categorical hot-spot finding differs from the 2017 finding in several ways:

- The 2023 finding replaces the single intersection scenario from the 2017 finding with four intersection scenarios based on truck percentage and road grade to allow for wider application of the finding.
- Each scenario in the 2023 finding has a rural or urban option. In contrast, the 2017 finding could only be applied in urban areas.
- The 2023 finding is based on a skewed intersection with cross streets at a 75-degree angle from each other, which allows for the finding to be applied to any intersection with an angle of 75 degrees or more. In contrast, the 2017 finding was based on a perpendicular (90 degree) intersection and could only be applied to intersections with an angle of exactly 90 degrees.
- The 2023 finding also modifies the acceptable ranges of modeling parameters based on FHWA's latest understanding of worst-case conditions. Table A- 1 compares the acceptable ranges of modeling parameters between the 2017 and 2023 findings.

Table A- 1. Acceptable Range of Modeling Parameters for 2017 and 2023 Findings

Parameter	Description	2017 Finding Acceptable Range	2023 Finding Acceptable Range
Analysis Year	The year when peak emissions are expected from the project when considered with background.	≥ 2017	≥ 2022
Area Type	An urban area has a population of 5,000 or greater within the FHWA adjusted urban area boundary.[13] All other areas are rural.	Urban	Urban or Rural
Road Grade (%)	The maximum grade along the approach, as measured from the stop line to a point 100 feet before the stop line along a line parallel to the direction of travel. Enter the maximum grade among the four approaches.	≤2%	≤6%

[13] A map of FHWA Adjusted Urban Areas can be found at https://hepgis.fhwa.dot.gov/fhwagis/ViewMap.aspx?map=MPO+Boundaries|FHWA+Adjusted+Urban+Area. More information on the FHWA definition of urban area can be found at https://www.fhwa.dot.gov/planning%20/processes/statewide/related/highway_functional_classifications/section06.cfm

Parameter	Description	2017 Finding Acceptable Range	2023 Finding Acceptable Range
Truck Percent (%)	The percentage of the total traffic volume that is made up of single unit and combination trucks. Enter the highest truck percentage from all links at the project intersection.	≥5%	≤20%
Temperature (°F)	Section 4.7.1 of EPA's 1992 CO Guideline[4] allows two methods: 1) temperature corresponding to each of the ten highest non-overlapping 8-hour CO monitoring values for the last 3 years, or 2) average January temperature	≥ -10°F	≤ 70°F
Speed (mph)	The average speed approaching the intersection during the peak hour. All intersection approaches must be within the acceptable range.	≥ 25 mph	15 mph ≤ speed ≤ 45 mph
Peak Hour Approach Volume (veh/hr)	The volume approaching the intersection during the peak hour. Enter the maximum among the four approaches.	≤ 2640	≤ 2640
Peak Hour Level-of-Service (LOS)	During the peak hour, the letter representing the quality of service for the entire intersection measured on an A-F scale, with LOS A representing the best operating conditions from the traveler's perspective and LOS F the worst.	A-E	A-E
Intersection Angle	Enter the smallest angle between the two cross-streets of the intersection (90 degrees is perpendicular).	= 90° (perpendicular intersections only)	≥ 75°
Number of through lanes (one direction)	The number of lanes approaching the intersection available for vehicles traveling through the intersection without turning. Enter the maximum among the four approaches.	≤ 4	≤ 4
Number of left turn lanes (one direction)	The number of lanes approaching the intersection that are designated for use only by vehicles making left turns. Enter the maximum among the four approaches.	≤ 2	≤ 2

Parameter	Description	2017 Finding Acceptable Range	2023 Finding Acceptable Range
Lane Width (feet)	The lateral distance between stripes for a single lane. Enter the minimum among all lanes at the intersection.	= 12 ft.	≥ 10 ft.
Median Width (feet)	The width of the area in the middle of a roadway separating opposing traffic flows.	= 0 ft. (no median)	Any (≥ 0ft)
1-Hour CO Background Concentration (ppm)	1-hour average concentration in the project area due to other local sources, determined in most cases from local monitoring data as described in Section 4.7.3 of EPA's 1992 CO Guideline. [4]	≤32.6	Varies by scenario and urban/rural (ranges from ≤ 27.7 to ≤32.0)
8-Hour CO Background Concentration (ppm)	8-hour average concentration in the project area due to other local sources, determined in most cases from local monitoring data as described in Section 4.7.3 of EPA's 1992 CO Guideline. [4]	≤7.3	Varies by scenario, urban/rural, and persistence factor (ranges from ≤ 1.70 to ≤6.90)
Persistence Factor	The factor used to calculate 8-hour concentration estimates from 1-hour concentration estimates, as determined by following Section 4.7.2 of EPA's 1992 CO Guideline. [4]	≤0.7	Any (0.0-1.0)