NCHRP Project 25-55

NCHRP Research Report 1058
Assessing Air Pollution Dispersion Models for Emissions Regulation

Appendix A
Air Quality Models and Field Studies with Suitable Datasets for Model Intercomparison

The National Cooperative Highway Research Program (NCHRP) is sponsored by the individual state departments of transportation of the American Association of State Highway and Transportation Officials. NCHRP is administered by the Transportation Research Board (TRB), part of the National Academies of Sciences, Engineering, and Medicine, under a cooperative agreement with the Federal Highway Administration (FHWA). Any opinions and conclusions expressed or implied in resulting research products are those of the individuals and organizations who performed the research and are not necessarily those of TRB; the National Academies of Sciences, Engineering, and Medicine; the FHWA; or NCHRP sponsors.

Please note that Appendix A refers to work completed under Phase I of Project 25-55 in 2018. The approach included here was modified substantially during the scoping and acceptance process for Phase II. In particular, the recommendations in Section 3.3 and the MIP outline in Section 4 at presented here differ substantially from the final product. This memo has not been substantively modified for inclusion as Appendix A to the final report, other than addition of headers labeling it as an appendix. Where conflicts exist, please refer to final products elsewhere in the final project report.

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TECHNICAL MEMORANDUM

To: NCHRP 25-55, Advisory Panel

From: John Zamurs (ZAMURS and ASSOCIATES), Edward Carr, Seth Hartley, Mike Brady (ICF International)

Date: October 26th, 2018

Subject: NCHRP 25-25, Assessment of Regulatory Air Pollution Dispersion Models to Quantify the Impacts of Transportation Sector Emissions, *Task 2 – Identify Air Quality Models and Field Studies with Suitable Datasets for Model Intercomparison for Transportation Projects*

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1. INTRODUCTION

The research carried out in this task has three main objectives as original identified in the amplified work plan:

- To identify and focus the model inter-comparison study on the most useful air quality models for analyzing transportation projects;
- To gather the best set of historical datasets developed on or near transportation facilities available for use in model testing and evaluation and identify data gaps for important transportation project types;
- Develop an outline for the structure of a model improvement program for the approval process for dispersion models used for air quality analysis of transportation projects

We have completed this research by gathering and reviewing information on historical ambient air quality and tracer studies on transportation focused air quality models. We have met the objectives of the study by carrying out the research as highlighted below:

- We reviewed twelve air quality models that in most cases have been developed for transportation project analysis. A subset of these models are characterized as to their key features and technical capabilities and from that list three models and one hybrid model are recommended for evaluation in subsequent tasks;
- From the dataset acquired and review of the monitoring studies we recommended the datasets for model inter-comparison. Where gaps in past monitoring studies have been

identified we provide recommendations on the transportation facility types for the tracer experiments to be performed in Task 6.

- We developed a model improvement outline specifically designed to consider use of air quality dispersion models for transportation projects

Details on the research are discussed in three main sections of the report: Air Quality Models, Field Studies and Outline for the Model Improvement Program. Within each section we provide recommendations on specific next steps for moving forward based on the findings from this research.

2. AIR QUALITY MODELS

We first identified a set of candidate project level air quality models suitable for the model inter-comparison study for transportation projects. The list of candidate models include all those listed on EPA's SCRAM Air Quality Dispersion Models Alternative Models list and those identified as preferred models for near road sources. This list includes: CALINE3, AERMOD, CAL3QHC/CAL3QHCR, and HYROAD. We also included the CALINE4 model as it enjoys widespread use in California and in many Asian countries. Our review considered several European models that have been developed over the past twenty years and by far the most widely used model with a full suite of capabilities is ADMS-ROADS and is included in the review. EPA announced in June of this year that they would be incorporating RLINE into AERMOD as a beta version to be released in the next update to AERMOD in 2019. This will provide a true line source capability, so a hybrid version was included in the review, AERMOD-RLINE. EPA's Office of Research and Development has in the past supported the development of the ROADWAY-2 model that is unique in that it is a numerical model and includes the most sophisticated treatment of vehicle wake turbulence. Finally, EPA has recently posted a screening version of the RLINE model called CLINE designed to support local communities and planners to get an initial assessment of near-source air quality impacts of transportation-related sources using national-scale inputs. We included this model given its ease of use and its support from EPA.

Table 2-1a and 2-1b provides a summary of the capabilities, features and relative scoring for each of the nine models considered for model selection. Table 2-1a focuses on the technical features of the model, while Table 2-1b identifies features that facilitate ease of use, functional capabilities and past model validation. Table 2-1c is a relative scoring table for the models technical and functional capabilities. Each element was rated based relative to the other models within the element. For example, ROADWAY-2 was assigned the highest rating for including traffic induced turbulent mixing as it has an explicit parameterization within the model for vehicle wake theory. Each element in the table is equally weighted so that the overall score is the simple sum of the eleven rating categories.

2.1. Recommended Air Quality Models for Inter-comparison Study

In our amplified work plan we identified that four air quality models would be evaluated in the inter-comparison study. The total score presented in Table 2-1c shows that the top four models are: ADMS-ROADS, CALINE4, AERMOD-RLINE and AERMOD based on a combination of model formulation and functionality. ADMS-ROADS is the highest ranking model due to the many features it offers and generally up to date technical features. Unlike, other models reviewed ADMS-ROADS does require a user to obtain either an annual license or permanent license for a nominal fee. CALINE4 offers a number of features but its model formulation is somewhat dated. AERMOD-RLINE and AERMOD are both technically sound models with the RLINE feature an important improvement. Their scores would be higher if they included capabilities to improve their usability in transportation settings. We include both versions of AERMOD with and without RLINE so as to fully explore the importance of the "true" line source algorithm.

While CALINE3 and CAL3QHC are still listed as a preferred models by EPA their selection over CALINE4 was determined based on the results from the New York City Route 9A roadway intersection study[1] which was not a tracer study. Tracer based evaluation studies such as EPA's study performed by Heist et al. (2013) *Estimating near-road pollutant dispersion: A model inter-comparison*. Trans. Res. Part D, 93-105, and data from the General Motors Sulfate tracer study (Benson, P.E., 1989. CALINE4 - a dispersion model for predicting air pollutant concentrations near roadways. California Department of Transportation. Report no. FHWA/CA/TL-84/15) have shown CALINE4 to produce superior statistical results across all statistical measures over CALINE3. This plus the review of functional facility type capabilities included in CALINE4 led to selection of CALINE4 over CALINE3 as one of the recommended models for the model inter-comparison study.

Thus the four models recommended for the model inter-comparison study are:

- ADMS-ROADS
- CALINE4
- AERMOD-RLINE
- AERMOD

[1] Sigma Research Corporation (1992) "Evaluation of CO Intersection Modeling Techniques Using a New York City Database", January. Under EPA Contract No. 68D90067.

Table 2-1a: Technical Features of Air Quality Models for Quantifying the Impacts of Transportation Emissions

	Model Formulation					
Model	**Geometry/ Characterization for On-road Mobile**	**Dispersion and Mixing Treatment**	**Traffic Induced Effects Included**	**Characterization of Mobile Source Emissions**	**Meteorology**	**Deposition and Chemistry**
CALINE3	Specify source/receptor heights, source length and mixing width; initial source height ± 10-m; below and above grade level treatment; surface roughness.	Gaussian diffusion; mixing zone over roadway plus 3-m for increased initial sigma-y; initial sigma-z increased by mixing zone residence time; sigma-z based on initial sigma-z and value of sigma-z at 10-km based on Pasquill-Gifford-Turner (PGT) dispersion curves; sigma-y standard PGT.	Includes uniform mixing region for turbulence and wake effects; constant traffic volume flow rate; no link to traffic model.	Emissions links with a specified distance, emission factor (g/mile), specified road width; no selective characterization for brake, tire, and re-entrained road dust emissions.	Hourly wind speed, direction, stability class, mixing height; uniform.	CO, PM - inert only, specify single deposition and settling velocity based on parameterization by Ermak (1977); no reactive decay treatment.
CALINE4	Improves CALINE3 by adding intersections, street canyon and parking facilities.	Improves over CALINE3 by adjusting initial sigma-z by residence time over roadway; initial sigma-z increased by mixing zone residence time; sigma-z based on initial sigma-z and value of sigma-z at a distance travelled by each line segment over the mixing zone based on Pasquill-Smith (1972) power curves with adjustment for vehicle	Improves CALINE3 by adjusting for residence time idle and vehicle heat flux effects on vertical dispersion; additional methods included for bluff or street canyons and parking lots.	Improves CALINE3 by adding an intersection module which includes vehicle idle, however this intersection modal emission calculation is considered outdated and no longer appropriate for today's vehicle fleet; again no selective characterization for brake, tire, and re-entrained road dust emissions.	Same as CALINE3 but with the addition of using sigma-theta (standard deviation in wind direction).	In addition to CO and PM, NO_2 option uses "Discrete Parcel Method" first-order reaction with sunlight and ozone.

	Model Formulation					
Model	**Geometry/ Characterization for On-road Mobile**	**Dispersion and Mixing Treatment**	**Traffic Induced Effects Included**	**Characterization of Mobile Source Emissions**	**Meteorology**	**Deposition and Chemistry**
		heat flux based on traffic volume; sigma-y parameterized based on observed sigma theta and Draxler (1972) Lagrangian diffusion time.				
CAL3QHC(R)	Same as CALINE3, but with intersection specification for queue links.	Same as CALINE3	Improves CALINE3 by adding traffic queuing algorithm that calculates queue length, delay, volume/capacity; R-version allows a year of traffic/signalization data, volume variation by hour/day of week. EPA considers the queuing algorithm to be dated and no longer applicable.	Improves CALINE3 by adding idling emissions while queued. Again, no selective characterization for brake, tire, and re-entrained road dust emissions.	Same as CALINE3. R-version allows a year of data.	Same as CALINE3
HYROAD	Detailed site-specific geometry; left and right turn bays, through lanes for all approach and departure links; turn movements, signal cycle timing, width of median, width of lanes, lane restrictions (e.g., HOV), pedestrian traffic crossing.	Lagrangian puff approach based on CALPUFF Gaussian puff formulation; puffs transported and dispersed under the varying signal phase conditions; vehicle-induced flows and wakes are incorporated into the model using methods developed by Eskridge (1987) creating non-uniform wind fields	Microscopic traffic simulation model, TRAF-NETSIM basis for generating traffic information; tracks vehicle speed and accel distributions by signal phase and 10-m roadway segment for use in emissions calculations and induced flows and turbulence; individual vehicles moved once a second to account for	Requires emission factors from MOVES as inputs, but speed distributions from the traffic module are based on MOBILE5/6 speed distributions determined from regression analysis for each time period. Model would need to be updated to work with available speed and accel	Wind speed, direction, sigma-theta, stability class, mixing height, temperature.	None.

	Model Formulation					
Model	**Geometry/ Characterization for On-road Mobile**	**Dispersion and Mixing Treatment**	**Traffic Induced Effects Included**	**Characterization of Mobile Source Emissions**	**Meteorology**	**Deposition and Chemistry**
		for puff advection, as well as enhanced vertical dispersion over roadways; initial sigma-y is the mean lane width of and sigma-z is set to 1.5 m.	traffic conditions; vehicle movements determined according to car-following logic based on neighboring vehicles, traffic control devices, and driver behavior; user supplied traffic volume; percent trucks, buses, autos.	distributions now available in MOVES. Spatial and temporal distribution of emissions is based on vehicle operation predictions rather than being uniformly distributed.		
AERMOD	Specification of area and volume source for line source modeling; enhanced interaction with terrain, surface CBL releases, building downwash (PRIME). Area sources may be modeled as multi-shaped convex polygons or circles.	Gaussian plume diffusion, numerical integration approach for area sources; initial sigma-y and sigma-z based on source size specification; improved parameterizations of: terrain interaction; building downwash (PRIME); urban dispersion (sensitive to population); CBL Gaussian in horizontal, bi-Gaussian probability density function in vertical; plume meander, low-wind speed treatment for volume sources, not implemented for area sources; uses of	None.	Specified by area (mass/area-s) or volume (mass/s); need to externally determine emissions from emission factor model; treats volume sources only in initial plume size by adding the square of the initial plume size to the square of the ambient plume size; if volume source is too close to receptor concentration not included "exclusion zone"; need to externally determine emissions from emission factor model.	Short-term, steady-state, emissions from a variety of industrial source type settings. Enhanced meteorological treatment, particularly for PBL using M-O length scale provides continuous stability variation. Also enhanced meteorological pre-processor to determine required inputs.	Has dry and wet deposition options based on Argonne National Lab (Weseley et al., 2001) and peer review (Waleck, et al., 2001); simple exponential decay user specified half-life.

	Model Formulation					
Model	**Geometry/ Characterization for On-road Mobile**	**Dispersion and Mixing Treatment**	**Traffic Induced Effects Included**	**Characterization of Mobile Source Emissions**	**Meteorology**	**Deposition and Chemistry**
		Bowen ratio (sensible heat flux/latent heat flux) and surface albedo. Use local upwind surface roughness's characteristics to influence dispersion characteristics.				
AERMOD-RLINE	Same as AERMOD but includes a "true" line source algorithm approximating a line as a series of point sources then applies Romberg integration of the point sources (Snyder et al., 2013).	Same as AERMOD but contains new formulations for the vertical and lateral dispersion rates (Venkatram et al., 2013) but in the absence of traffic; includes parametrization for low wind meander. Databases used to develop model parametrizations include Idaho Falls, Prairie Grass, Raleigh, Detroit and Phoenix Field studies. Along with wind tunnel experiments of Heist et al. (2009).	None.	Same as AERMOD but models line source as series of point sources over which the model integrates.	Same as AERMOD	Same as AERMOD

	Model Formulation					
Model	**Geometry/ Characterization for On-road Mobile**	**Dispersion and Mixing Treatment**	**Traffic Induced Effects Included**	**Characterization of Mobile Source Emissions**	**Meteorology**	**Deposition and Chemistry**
ADMS-ROADS	ADMS decomposes line sources such as roadways into a series of elements whose spacing depends on the source-receptor distance. Each element's contribution to the concentration at a given receptor is approximated by a finite line source aligned perpendicular to the wind direction. Other elements characterized by the model include surface roughness and building wake effects. Area and volume sources may be modeled as convex polygons with up to 50 vertices.	Similar model formulation as AERMOD uses similarity based boundary layer theory (M-O) and computes steady state Gaussian solutions (non-Gaussian in the vertical for convective conditions as with AERMOD) to describe the turbulent mixing of pollutants.	Includes algorithms to account for traffic-produced turbulence, the presence of roadside barriers, and an integrated street canyon module and tunnels.	Emission datasets have been incorporated into the software for the European emissions model COPERT (latest version 5.0). Traffic information can be directly entered to model but emission factors are in g/km, speeds in km/hr. Hourly traffic flow can be directly entered into the model.	Roughness length, wind speed, wind direction, and then one of the following: cloud cover, sensible heat flux, or M-O length.	Has dry and wet deposition options; also includes NOx based on Generic Reaction Set developed by Venkatram et al., (1994) and sulfate chemistry based on EMEP model (Tsyro, 2001).
C-LINE	Limited functionality or roadways	Analytical form of RLINE model	None	Uses national database information on fleet mix, traffic volume, and emission factors from MOVES.	None	None

	Model Formulation					
Model	**Geometry/ Characterization for On-road Mobile**	**Dispersion and Mixing Treatment**	**Traffic Induced Effects Included**	**Characterization of Mobile Source Emissions**	**Meteorology**	**Deposition and Chemistry**
ROADWAY-2	Simple divided highway approach; user specifies number of lanes, width of lanes, orientation, traffic volume and speed, plus vehicle dimension. ROADWAY uses a finite difference method to solve the conservation of mass equations.	Grid based numerical model that is capable of handling complex wind flow fields and near-calm conditions. Uses similarity based boundary layer theory (M-O); incorporates into the boundary layer model with turbulent kinetic energy closure and surface parameterizations to derive the mean and turbulence profiles from input meteorological data; includes an explicit treatment of vehicle wake theory to account for vehicle induced wake turbulence.	Yes - includes wake parameterization scheme derived from vegetation canopy flow theory and wind tunnel measurement of vehicle wakes by Eskridge and Thompson (1982) and Eskridge and Rao (1983).	User must supply vehicle emission rates (g/veh-km) - only single value.	Roughness length, wind speed and wind direction, temperature and two height upwind of the highway. Use similarity theory with these variables to describe the basic state atmosphere on which to overlay changes from the vehicle wake effects are added.	Simple chemical mechanism for NOx is included using a two-step mechanism.

accel = accelerate, ADMS = Atmospheric Dispersion Modeling System, AERMOD = American Meteorological Society/Environmental Protection Agency Regulatory Model, CBL = convective boundary layer, CO = carbon monoxide, C-LINE = Community-LINE Source Model, EPA = U.S. Environmental Protection Agency, g = gram, hr = hour, m = meter, M-O = Monin-Obukhov, NO_2 = nitrogen dioxide, PBL = planetary boundary layer, PGT = Pasquill-Gifford-Turner, PM = particulate matter, PRIME = Plume Rise Model Enhancements, s = second, veh-km = vehicle-kilometer

Table 2-1b: Functional Features of Air Quality Models for Quantifying the Impacts of Transportation Emissions

	Practical Considerations For Model Use for Transportation Professionals			Other Considerations				
Model	**Input Requirements**	**Effort to Develop Inputs**	**Available Interfaces**	**Range of Applicability**	**Background Concentrations**	**Public Domain and Status of Support**	**Historical Model Performance for Mobile Sources**	**Facility Type of Environments**
CALINE3	Minimal - meteorology, traffic volumes, facility type layout configuration, emission factors.	Modest	FHWA CAL3 Interface	Few meters to 150-m from roadway; lowest wind speed 1.0 m/s	Single hourly background concentration specified by user	Publicly available from EPA website, not supported or maintained by EPA. Most recent version from 08/07/1989.	Widely evaluated in more than half a dozen model validation studies in both tracer and ambient CO studies.	At-grade, depressed, bridge
CALINE4	Minimal - similar to CALINE3 but with the need for measurement of standard deviation in hourly wind direction. Intersection mode requires accel and decel times.	Modest	Caltrans CL4 Interface and commercial software from Lakes Environmental CALRoads View.	Few meters to 500-m from roadway; lowest wind speed 0.5 m/s	Single hourly background concentration specified by user	Publicly available from Caltrans website, minimally supported by Caltrans. Most recent version from 06/1989.	Widely evaluated in more than half a dozen model validation studies in both tracer and ambient CO studies. Generally, it has been shown to have modest improvement over CALINE3 model. It is still the referred model in California for microscale air quality analysis.	At-grade, depressed, bridge, parking lot, intersection (this requires user input on decel and accel time not generally known)
CAL3QHC(R)	Minimal - meteorology, traffic volumes, facility type layout configuration, signal cycle timing, emission factors.	Modest	FHWA CAL3 Interface and commercial software from Lakes Environmental CALRoads View.	Few meters to 150-m from roadway; lowest wind speed 1.0 m/s	Single hourly background concentration specified by user	Publicly available from EPA website, not supported or maintained by EPA. Most recent version from 07/15/2013.	EPA selected this version over CALINE4 based on results from the 1992 "Evaluation of CO Intersection Modeling Techniques Using A New York City Database" publication. Limited validation testing has	At-grade roadways and intersections

	Practical Considerations For Model Use for Transportation Professionals			Other Considerations				
Model	**Input Requirements**	**Effort to Develop Inputs**	**Available Interfaces**	**Range of Applicability**	**Background Concentrations**	**Public Domain and Status of Support**	**Historical Model Performance for Mobile Sources**	**Facility Type of Environments**
							occurred since that time. EPA considers queuing algorithm dated and no longer applicable.	
HYROAD	Moderate - Requires similar information as CAL3QHC but also requires more detailed information on traffic control signal intervals, duration, control code, etc.	Moderate	User Interface Available also on EPA website can be used to model roadway intersections with up to five approach and departure legs for short-term high concentration episodes.	Few meters to 500-m from roadway; lowest wind speed 0.3 m/s	Single hourly background concentration specified by user	Publicly available from EPA website, not supported or maintained by EPA. Most recent version from 06/28/2002.	Extensive model performance evaluation done under NCHRP 25-6 as reported in the model formulation document chapter 5. Results showed HYROAD puff formulation superior to CAL3QHC.	Roadway intersections
AERMOD	Extensive - requires pre-processing meteorological data via AERMET for both surface and upper-air meteorological data. Requires developing and converting MOVES data from g/mi to g/unit area or g/s	Large	Commercial GUI software from Lakes Environmental AERMOD View and BEEST.	Tens of meters up to 50 km	Temporally varying background concentration specified by user and can also be specified by wind sector	MOVES	Limited - EPA evaluated AERMOD as the replacement for CALINE3/CAL3QHC using the Idaho Falls Tracer Study (barriers only with no traffic) and the Caltrans Highway 99 Tracer study. AERMOD has only limited model evaluation studies for near ground level releases only for the Prairie Grass Study.	None in particular. Most easily setup for parking areas and truck and bus terminals.

	Practical Considerations For Model Use for Transportation Professionals			Other Considerations				
Model	**Input Requirements**	**Effort to Develop Inputs**	**Available Interfaces**	**Range of Applicability**	**Background Concentrations**	**Public Domain and Status of Support**	**Historical Model Performance for Mobile Sources**	**Facility Type of Environments**
	if modeled as volume source. Requires development of terrain heights. The use of AERMAP facilitates this process.							
AERMOD-RLINE	Same as AERMOD, but with the emission rate for the "true" line sources specified as g/(m-s).	Large	Likely Lakes Environmental will update GUI within a few months of when this version of AERMOD is released in 2019.	Tens of meters up to 500-m for RLINE portion	Single hourly background concentration specified by user	Currently unavailable, but expected to be released in 2019 in the next public release of AERMOD as a beta option. A beta version is a peer-reviewed option potentially ready for consideration as an alternative model and as the next step before formal promulgation as a regulatory option.	Same as AERMOD, but with the additional note that the Idaho Falls and Prairie Grass tracer experiments and Raleigh, Detroit, and Phoenix Field studies were used in developing the parametrizations for the dispersion coefficients. These databases should therefore not be used in the model comparison evaluation.	Straight roadways; series of straight lines to simulate a curved roadway. EPA working to incorporate barriers (sound walls) and depressed roadway in 2019 but as an "alpha" option which is for testing and evaluation that is experimental.

	Practical Considerations For Model Use for Transportation Professionals			Other Considerations				
Model	**Input Requirements**	**Effort to Develop Inputs**	**Available Interfaces**	**Range of Applicability**	**Background Concentrations**	**Public Domain and Status of Support**	**Historical Model Performance for Mobile Sources**	**Facility Type of Environments**
ADMS-ROADS	Requires similar level of data input as AERMOD but user interface simplifies process. However, conversion would be needed to move from English system to metric system. Not set up to directly interface with MOVES, but COPERT is similar but with different categories.	Moderate	GUI is incorporated into the software price for use of the model. GUI includes links to ArcGIS and MapInfo Professional GIS.	Few meters to hundreds of meters.	Hourly background concentrations may be added as specified by the user	Latest version of model publicly released on the CERC website is ADMS-Roads Version 4.1 (December 2017). License fee to use the software includes the GUI. Annual and permanent licenses are available.	Extensive set of model performance evaluation studies for the ADMS and at least three papers specifically targeted to ADMS-ROADS. EPA/ORD paper Heist, et al. (2013) "Estimating near-road pollutant dispersion: A model inter-comparison". Trans. Res. Part D, 93-105; Stocker, et al, (2013) "Road Source Model Intercomparison Study Using New and Existing Datasets", 15th Conference on Harmonization with Atmospheric Dispersion Modeling for Regulatory Purpose, Madrid, Spain, May 6-9, 2013 and Ellis, K. et al., (2001) "Comparison of ADMS-Roads, CALINE4 and UK DMRB Model Predictions for Roads".	Roads entered as a series of links. Up to 50 vertices may be specified for each roadway. Road types are available but are defined by geographic regions in the UK (e.g. Scotland (urban, rural, motorway).

	Practical Considerations For Model Use for Transportation Professionals			Other Considerations				
Model	Input Requirements	Effort to Develop Inputs	Available Interfaces	Range of Applicability	Background Concentrations	Public Domain and Status of Support	Historical Model Performance for Mobile Sources	Facility Type of Environments
C-LINE	Minimal, only location, traffic volume, speed and fleet mix.	Minimal	None - web-based model tool	Few meters to hundreds of meters.	None	Publicly available model for use as a screening tool. Must be a registered CMAS user to access the model.	None reported - identified as an analytical version of R-LINE dispersion model.	Major roadways
ROAD-WAY-2	Modest - roughness length, temperature at two heights, wind speed and direction, number of traffic lanes median width, orientation, traffic volume, vehicle speed.	Modest	None	Few meters to a few hundreds of meters downwind.	Single background concentration specified by user	Not maintained, as the last version of ROADWAY-2 was available through NOAA Air Resource Laboratory.	ROADWAY-2 was evaluated using the GM Sulfate experiment data. Overall performance was found to be satisfactory, although oblique wind angles caused the most problems.	Divided highway or freeways

accel = accelerate, ADMS = Atmospheric Dispersion Modeling System, AERMOD = American Meteorological Society/Environmental Protection Agency Regulatory Model, Caltrans = California Department of Transportation, CERC = Cambridge Environmental Research Consultants, CMAS = Community Modeling and Analysis System, CO = carbon monoxide, C-LINE = Community-LINE Source Model, decel = decelerate, EPA = U.S. Environmental Protection Agency, g = gram, GUI = graphical user interface, hr = hour, m = meter, NOAA = National Oceanic and Atmospheric Administration, PRIME = Plume Rise Model Enhancements, s = second

Table 2-1c: Rating of Air Quality Models for Quantifying the Impacts of Transportation Emissions

Model	Model Formulation						Practical Considerations of Model Use for Transportation Professionals		Other Considerations			Total Score
	Geometry/ Characterization for on-road mobile	Dispersion and Mixing Treatment	Traffic Induced Effects Included	Characterization of Mobile Source Emissions	Meteorology	Deposition and Chemistry	Effort to Develop Inputs	Background Concentrations	Public Domain and Status of Support	Historical Model Performance for Mobile Sources	Facility Type of Environments	
CALINE3	3	3	3	3	2	3	3	3	3	3	4	33
CALINE4	3	4	4	4	3	4	3	3	4	4	5	**41**
CAL3QHC(R)	3	3	3	3	2	3	3	3	3	3	4	33
HYROAD	4	4	4	3	3	0	2	3	2	3	3	31
AERMOD	4	4	0	2	5	5	1	4	4	4	3	**36**
AERMOD-RLINE	5	5	0	2	5	5	1	4	4	4	3	**38**
ADMS-ROADS	5	4	4	3	5	5	1	4	3	4	5	**43**
C-LINE	2	4	0	3	1	1	5	0	3	0	0	19
ROADWAY-2	3	4	5	2	4	2	4	3	2	3	2	34

Scoring:

1 = outdated or very limited functionality
2 = somewhat dated or limited functionality
3 = average
4 = good/near state of the science or good set of functionalities
5 = best/state of the science or excellent functionalities for traffic analyst
0 = N/A

3. FIELD STUDIES

The research team sought first to identify air quality datasets that were suitable for the model comparison and evaluation study. To be of value to this research the air quality datasets need to have been performed in transportation settings. Two types of air quality datasets were examined: tracer experiments and ambient air quality monitoring of air pollutants.

- Tracer studies involve the controlled release of a gas that is uncommon in the air (or has very low background levels) and easily measured downwind of the release location. Measurements of meteorological conditions are also conducted during the tracer release. The same conditions are then simulated with air pollutant models and the observed and predicted concentrations are compared.

- Ambient air quality monitoring studies measure concentrations of air pollutants along with background air concentrations and meteorology so as to isolate emissions and the associated air concentrations due solely to the transportation setting. However, since the emission rates are not measured (or controlled) the emissions are inferred from emission factor models (e.g., MOVES and EMFAC) introducing additional uncertainty in the understanding of the limitations of the air quality dispersion models to simulate air concentrations in transportation settings.

The objective in identifying historical tracer studies was to identify data gaps in the set of available field studies conducted in transportation settings and that would potentially benefit from new tracer experiments. The transportation settings of primary concern are:

- Intersections
- Interchanges
- Skewed intersections
- Freeways
- Arterials
- Truck and Bus terminals

The ambient air quality monitoring studies are considered supplemental to tracer experiments with the idea that modeling of a few select past ambient air quality monitoring studies could provide additional weight of evidence for a preferred air quality model for transportation projects. We first discuss the data gathering and review of historical tracer studies.

3.1. Historical Tracer Studies

When performing a roadway air quality study, the modeling chain is subject to uncertainty at every step— perhaps the largest source of uncertainty is the emission source strength, but also turbulent mixing and diffusion, deposition and chemical transformation of air pollutants. This makes it difficult to isolate and evaluate just the dispersion component of the analysis. Using data from tracer studies eliminates a major source of uncertainty in the modeling chain and allows the dispersion model to be evaluated on its ability to characterize the advection and turbulent mixing of air pollutants released into the environment. Tracer studies are also EPA's preferred method for model evaluation. Because tracer studies remove uncertainty with the emission source strength and background, they are ideal for testing and evaluating the dispersion component of air pollutant modeling.

Air quality modeling for transportation projects addresses many facility types, which may be best served by different models. Roadways are typically "line" sources with roughly continuous emissions. Truck and bus terminals may require different treatment, such as an area source. One type of air quality model may not always be the best for the different type projects found in the transportation sector.

Both of the tracer datasets used in EPA's technical support document for the replacement of CALINE3 with AERMOD for transportation-related air quality analyses consisted of a freeway facility type. Details of the two datasets are as follows:

- The California DOT (Caltrans) Highway 99 tracer study, performed in a mostly rural to suburban location with an annual average daily traffic (AADT) rate of just 35,000 and closest receptor at 50 meters (m) from the roadway.

- The Idaho Falls line-source tracer study representing a rural freeway (but without vehicles) at Idaho Falls National laboratory with the nearest receptor at 15 m.

This limited number of tracer datasets does not adequately address many facility types (e.g., intersections, interchanges, arterials) and land-use settings (e.g., urban, suburban) that should be considered to make definitive and robust decisions on model selection[2]. To support the testing and evaluation of air quality models for transportation projects additional tracer studies are needed. The most common project-level facility types of interest for model evaluation against tracer data are:

- Intersections
- Interchanges
- Skewed intersections
- Freeways
- Arterials
- Truck and bus terminals

As a first step, the Research Team conducted an extensive literature review of possible tracer studies conducted in the near-roadway environment both domestically and internationally. For those that looked promising for the needs of this study, the Research Team sought to acquire the tracer data along with details of the experiment from the research organization or the authors of the study. The details of those efforts are discussed below.

[2] Also, the limited number of vehicles in both of these studies, zero and just 35,000 AADT, make the results questionable in applying to high traffic environments.

3.1.1. Literature Review

The approach to search for candidate tracer studies focused on key word searches associated with tracer studies and transportation terms and air quality modeling. The Research Team phased the literature review approach through three search strategies: broad, medium, and narrow.

In the broad strategy, the Research Team developed a list of terms related to tracers, transportation, and emissions and dispersion, drawing from key terms used in previously known tracer datasets (e.g., Caltrans Highway 99 tracer study). The Research Team combined these terms to perform searches in Web of Science and EbscoHost, two online databases with digital libraries of generally peer-reviewed publications that are licensed professional publishers recognized by library professionals. The Research Team refined the search results by Web of Science Categories and Ebsco Subjects. In the medium strategy, the Research Team further refined the search strategy by adding "NOT" terms to reduce the number of health-related studies or tracer studies in environmental media not of interest. In the narrow search strategy, the Research Team performed a keyword analysis on ten references deemed relevant. The Research Team removed terms that were not keywords from the ten relevant references to further refine the results.

The specific search terms used in both database searches for the narrow search strategy are presented in Table 3-1, and the summary count of results are presented in Table 3-2. The searches were not limited by date or language.

Table 3-1: Literature Search Strings for Bibliographic Literature

	Search String
Narrow	("tracer") AND ("roadway" OR "road" OR "intersection" OR "freeway" OR "vehicle" OR "traffic") AND (("emission" OR "dispersion") NOT ("emission tomography")) NOT ("rat" OR "mouse" OR "patient" OR "groundwater" OR "ocean" OR "indoor" OR "soil")
Web of Science	**Refined by: Web of Science Categories**: (environmental sciences OR meteorology atmospheric sciences OR engineering environmental OR engineering civil OR transportation science technology OR multidisciplinary sciences OR transportation OR environmental studies OR geosciences multidisciplinary)
EbscoHost	**MEDLINE database excluded** **Refined by: Ebsco Subjects:** (environmental aspects OR carbon monoxide OR transportation: demand, supply, and congestion; travel time; safety and accidents; transportation noise OR air pollution; water pollution; noise; hazardous waste; solid waste; recycling OR emission exposure OR lung disease prevention OR air pollution OR air quality)

Table 3-2: Summary of Results for Bibliographic Literature

Search Type	Database	Number of results, broad search	Number of results, medium search	Number of results, narrow search
Bibliographic Literature	EbscoHost	16	13	8
	Web of Science	299	246	167

Date of search: 8/9/2018

Grey literature searched included government reports, research institutions, and commercial entities. In order to identify potentially relevant grey literature, the Research Team searched the internet via Google using keyword search strings similar to those used for the bibliographic database searches. The Research Team performed the keyword searches using the non-periodical literature search terms noted in Table 3-3 for the organizations listed in Table 3-4. The estimated number of results for each organization is also presented in Table 3-4. The Research Team retrieved up to the highest 100 matches for each organization's site.

Table 3-3: Literature Search Strings for Non-Periodical Literature

Search Type	Database	Search String
Non-Periodical Literature	Organization's Domains (see Table 4)	("tracer") AND (roadway OR road OR intersection OR freeway OR freeway OR motorway OR vehicle OR automobile OR "car" OR "truck" OR "bus" OR motorcycle OR traffic OR transportation) AND (emission OR exhaust OR dispersion OR mixing OR meteorology OR deposition) AND site: "Domain" NOT (tape OR wire)

Date of search: 8/9/2018

Table 3-4: List of Organizations Included in the Non-Periodical Literature Search

Organization	Results
U.S. Federal Government	
U.S. Department of Transportation	87
U.S. Environmental Protection Agency	290
Total	377
U.S. State Government	
Alaska Department of Transportation	0
Arizona Department of Transportation	15
California Department of Transportation	206
Colorado Department of Transportation	16
Florida Department of Transportation	11
Illinois Department of Transportation	2
Minnesota Department of Transportation	78
New York Department of Transportation	112
Virginia Department of Transportation	4
Washington State DOT Home Page	29
Total	473
Research Institutions	
Center for Transportation Research	0
Coordinating Research Council	43
ITRE: UNC Institute for Transportation Research and Education	0
Texas Transportation Institute	13

Organization	Results
UC Davis Institute of Transportation Studies	1
UC Riverside CE-CERT	31
Virginia Tech Transportation Infrastructure & Systems Engineering Division	2
Total	90
Commercial Entities	
BMW	0
Daimler	0
Fiat Chrysler Automobiles	1
Ford Motor Co.	3
General Motors Co.	9
Honda Motor Co.	0
Nissan	0
Toyota	14
Volkswagen	0
Total	27
TOTAL	967

The literature review of EbscoHost, Web of Science, and the grey literature includes both domestic and international studies of tracer studies targeted to the near-roadway environment. While some of these datasets are quite old, unlike emissions, the dispersion properties remain current. The Research Team found numerous tracer studies for transportation projects, some of which are not relevant given they took place at the regional scale (entire cities) or were focused on urban street canyons. In addition, in the process of reviewing the literature we uncovered a number of wind tunnel tracer studies that we have included in a separate Table 3-8. The wind tunnel tracer studies are primarily for informational purposes, but these studies could potentially be used in the model inter-comparison studies.

We present in Table 3-5 only those tracer studies relevant to project facility types of interest to this study. The table presents information related to the facility layout for each tracer experiment. Table 3-6 presents information related to the tracer release and the status of the data acquisition for each tracer experiment. Table 3-7 presents the total number of tracer experiments conducted by transportation facility type. The Research Team has acquired 11 datasets from the tracer experiments, each of which are comprised of data on tracer gas concentration with concurrent measurements of meteorology and traffic conditions. We are still in the process of connecting with one research group to determine the availability of the datasets for the tracer experiments that they conducted.

Table 3-5: Facility Description of Tracer Experiments

Reference[1]		Facility Description				
Article Title	**Author(s)**	**Facility Type**	**Experiment Date(s)**	**Location**	**Facility Layout**	**Traffic Volume (AADT)**
The Mammoth Lake Route 203 Transportation Project: A Case Study in Air Quality Modeling and Mitigation	Benson, Nokes, Cramer	Arterial, freeway, intersection	1/12/1984, 2/7/1984, 3/22/1984	Mammoth Lakes, CA	• State Route 203 and Lake Mary Road • 1,600 m section • From the east boundary of the tracer release to the Lake Mary road intersection, Route 203 has two lanes in each direction with a two-way left turn lane between. From the Lake Mary Road intersection to the north and west boundaries, there is one lane in each direction with no median. • Nearby terrain is mountainous with slope generally sloping downhill from the west • Surrounding area is characterized by strip commercial development along Route 203 and Lake Mary Road with residential property behind. • The structures are built in mature conifer forest.	15,700
General Motors Sulfate Dispersion Experiment: Experimental Procedures and Results	Cadle et al.	Freeway	9/29/1975 - 10/30/1975	Milford, MI	• 10,000 m long test track • North-South straightaway • Lightly wooded, rolling hills • Equivalent of a four-lane freeway • Two lanes in opposite directions • 11.8-m median	135,408
Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways	Dabberdt et al.	Freeway	1/17/1975 - 2/5/1975	Santa Clara, CA	• U.S. Highway 101 • Midway between the Lawrence and San Tomas Expressways • 36.6-m wide road • Grade-level • Three lanes of traffic in each direction • Relatively simple, flat, and homogeneous	100,000
Analyses, Experimental Studies, and	Dabberdt et al.	Freeway	7/2/1975 - 7/22/1975	San Jose, CA	• I-280 • Depressed, cut-section segment • 8.2 m deep and about 56 m wide	Unknown

Reference[1]		Facility Description				
Article Title	Author(s)	Facility Type	Experiment Date(s)	Location	Facility Layout	Traffic Volume (AADT)
Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways					• Five eastbound lanes and six westbound lanes • Neighboring terrain is primarily one- and two-story suburban residences	
CALINE4 - A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways[5]	Benson	Freeway	12/23/1981 - 3/24/1982	Sacramento, CA	• Caltrans Highway 99 experiment • 2.5 mile straight road test section on a seven mile loop • Open fields and parks to the north and scattered residential to south • Two lanes in each directions • 14-m median • Roadway width totals 28.6 m	35,000
Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways	Dabberdt et al.	Freeway, interchange	8/12/1975, 9/3/1975	San Jose, CA	• I-280 • Elevated viaduct section • Six lanes of traffic flow eastbound and five westbound (including a double on-ramp)	Unknown
Intersection Air Quality Modeling	Carr, Johnson, Ireson	Intersection	2/18/1994 - 3/03/1995	Tucson, AZ	• 22nd Street and Alvernon Way • Alvernon Way runs north and south • 22nd Street runs east and west • All approaches have two or more lanes with separate left turn bays • Suburban • Surrounding structures within 1,000 m of the intersection were low rising one and two-story office buildings, homes, businesses and apartment	82,000

Reference[1]		Facility Description				
Article Title	**Author(s)**	**Facility Type**	**Experiment Date(s)**	**Location**	**Facility Layout**	**Traffic Volume (AADT)**
Intersection Air Quality Modeling	Carr, Johnson, Ireson	Intersection	12/07/94 - 3/12/95	Denver, CO	• Hampden Avenue (U.S. 285) and University Boulevard (State Hwy 177) • Line source release at high-volume intersection • University runs north and south • Hampden runs east and west • Both are divided roadways • Surrounding area consists of houses set back more than 50 m from the roadway, a thin grassy field of 0.5-0.5 m in length, sidewalk, and then an immediate 8-foot wall which is backed against 15-25 foot-tall trees	99,000
Intersection Air Quality Modeling	Carr, Johnson, Ireson	Intersection	1/1995 - 3/1995	Loudon County, VA	• Route 28 (Sully Road) and Route 606 (Old Ox Road) • Line source release at high-volume intersection • Route 28 runs north and south • Route 606 runs east and west • Both are divided roadways • Rural • Surrounding area consists of an open grassy fields of 0.5 - 1.0 m in length, 15 to 20-foot tail pine trees within about 75 feet of the roadway	83,000
Vehicle Emissions at Intersections	Bullin, Hinz, Bower	Intersection	11/03/80 - 5/18/81	College Station, TX	• Corner of Texas Avenue, Jersey Street, and Kyle Street • Urban setting • Intersection surrounded by trees and single-story buildings in all but the northwest quadrant, which contained a golf course	Unknown
Vehicle Emissions at Intersections	Bullin, Hinz, Bower	Skewed intersection	9/28/81 - 10/14/81	Houston, TX	• Corner of Woodway Boulevard and South Post Oak Lane • Urban setting • Surrounding area consists of 7- to 24-story buildings, a service station, and a two-story apartment building	Unknown

Reference[1]		Facility Description				
Article Title	**Author(s)**	**Facility Type**	**Experiment Date(s)**	**Location**	**Facility Layout**	**Traffic Volume (AADT)**
Estimation Of Road Traffic Emission Factors From A Long Term Tracer Study	Belalcazar et al.	Arterial	1/2007 - 3/2007	Ho Chi Minh City, Vietnam	• Urban street canyon • Bait Thang Hai Street • Highly congested two-way street • Three lanes each way • Transited by motorcycles, cars, busses, and trucks • Sidewalks are 4 m wide • Street is 16 m wide • Surrounding buildings average a height of 14 m with occasional open space between them • Surrounding trees on both sides of street average a height of 28 m	Unknown
Introduction to the DAPPLE Air Pollution Project	Arnold et al.	Arterial, intersection	5/15/2003	London, UK	• Perpendicular intersection of Marylebone Road and Gloucester Place • Busy dual carriageway • 38 m wide • Up to seven lanes wide including the bus lanes • Marylebone forms the northern boundary of the London Congestion-Charging Zone • Gloucester is a three-lane road approximately 20 m wide with traffic flow one-way to the north	Unknown
Short-range Urban Dispersion Experiments Using Fixed and Moving Sources	Shallcross et al.	Arterial, intersection	11/2/2004	London, UK	• Marylebone Road near Gloucester Place • Tracer released from two fixed point sources, one at street level and one at roof level • Average height of buildings in area was 22 m	Unknown
Short-range Urban Dispersion Experiments Using Fixed and Moving Sources	Shallcross et al.	Arterial, intersection	11/11/2004	London, UK	• Fixed point roof source was used in conjunction with releases from a car moving along Marylebone and Gloucester • Average height of buildings in area of interest is 22 m	Unknown

Reference[1]		Facility Description				
Article Title	**Author(s)**	**Facility Type**	**Experiment Date(s)**	**Location**	**Facility Layout**	**Traffic Volume (AADT)**
Near-road Multipollutant Profiles: Associations Between Volatile Organic Compounds and a Tracer Gas Surrogate Near a Busy Highway	Barzyk et al.	Freeway	8/7/2006 - 8/8/2006	Raleigh, North Carolina	• I-440 limited-access freeway • An open field at-grade with the freeway extends for approximately 120 m to the north of I-440 • Only a guardrail and shrubbery approximately 1 m in height and width between the field and I-440 travel lanes	125,000
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon	Okamoto et al.	Arterial	11/1975	Tokyo, Japan	• Urban street canyon • One-way road in the Kanda-Nishikicho area • Focus was on the effects of buildings on the distribution of air pollutants, not the effects from roadway configuration and/or traffic • Street width of 22 m • Nine-story building was the highest point of street canyon • 48 hours total release	24,000
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon	Okamoto et al.	Arterial	12/1980	Tokyo, Japan	• Urban street canyon • Aoyama Street (Route 246) experiment • Street width of 40 m • 12-story building was the highest point of street canyon • Two 40-hour continuous experiments	80,000
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon	Okamoto et al.	Arterial	2/1981	Tokyo, Japan	• Urban street canyon • Sotobori Dori Street • Nishi-Shinbashi program • Focus was on understanding the precise distribution of NOx concentrations in densely built-up areas • Street width of 32 m • Nine-story building was the highest point of street canyon	45,000

Reference[1]		Facility Description				
Article Title	**Author(s)**	**Facility Type**	**Experiment Date(s)**	**Location**	**Facility Layout**	**Traffic Volume (AADT)**
CityFlux Perfluorocarbon Tracer Experiments	Petersson et al.	Arterial, intersection	6/2006	Manchester, UK	• Regional scale (city-wide) • Office block is surrounded by trafficked streets on three sides and a multi-story car park on the other • Intensively developed high density urban area with 2-5 story, attached or very close-set buildings often of brick or stone	Unknown
CityFlux Perfluorocarbon Tracer Experiments	Petersson et al.	Arterial, intersection	6/27/2006	Manchester, UK	• Same facility layout as other Petersson et al. experiment	Unknown

AADT = annual average daily traffic, m = meter, NOx = nitrogen oxides
[1] Note that in some instances the same reference is cited for multiple tracer experiment datasets. This is because some articles discuss multiple experiments that occurred on different dates and/or locations.

Table 3-6: Tracer Gas Description and Status of Data Acquisition

Reference[1]		Tracer Description					Data Acquired				
Article Title	Author(s)	Gas	Release Intervals (#)	Time of Release Interval (minutes)	Measurement Locations (#)[2]	Range of Distances from Measurement Locations to Facility (m)[3]	Tracer Concentration	Meteorology	Traffic Volume	Traffic Speed	Vehicle Type
The Mammoth Lake Route 203 Transportation Project: A Case Study in Air Quality Modeling and Mitigation	Benson, Nokes, Cramer	SF6	16	30	9	544 m southeast of intersection - 371 m northwest of intersection	✓[4]	✓	✓	✓	✓
General Motors Sulfate Dispersion Experiment: Experimental Procedures and Results	Cadle et al.	SF6	62	30	20	100 m east of roadway edge - 30 m west of roadway edge	✓	✓	✓	✓	✓
Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways	Dabberdt et al.	SF6, F13B1	45	60	20	122 m north of roadway edge - 120.8 m south of roadway edge	✓	✓	✓	✓	✓
Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways	Dabberdt et al.	SF6, F13B1	50	60	35	Within and adjacent to the roadway	✓	✓	✓	✓	✓

Reference[1]		Tracer Description					Data Acquired				
Article Title	Author(s)	Gas	Release Intervals (#)	Time of Release Interval (minutes)	Measurement Locations (#)[2]	Range of Distances from Measurement Locations to Facility (m)[3]	Tracer Concentration	Meteorology	Traffic Volume	Traffic Speed	Vehicle Type
CALINE4 - A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways[5]	Benson	SF6	56	30	10	200 m east of roadway edge - 200 m west of roadway edge	✓	✓	✓	✓	✓
Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways	Dabberdt et al.	SF6, F13B1	64	60	34	Within and adjacent to the roadway with nine sampling locations around the westbound on-ramp and one location around the eastbound on-ramp	✓	✓	✓	✓	✓
Intersection Air Quality Modeling	Carr, Johnson, Ireson	SF6	136	15	18	93 m northwest of intersection center - 171 m southeast of intersection center	✓	✓	✓	✓	✓
Intersection Air Quality Modeling	Carr, Johnson, Ireson	SF6	154	15	20	144 m southwest of intersection center - 117 m northeast of intersection center	✓	✓	✓	✓	✓
Intersection Air Quality Modeling	Carr, Johnson, Ireson	SF6	104	15	24	181 m northeast of intersection - 136 m southeast of intersection	✓	✓	✓	✓	✓

Reference[1]		Tracer Description					Data Acquired				
Article Title	Author(s)	Gas	Release Intervals (#)	Time of Release Interval (minutes)	Measurement Locations (#)[2]	Range of Distances from Measurement Locations to Facility (m)[3]	Tracer Concentration	Meteorology	Traffic Volume	Traffic Speed	Vehicle Type
Estimation Of Road Traffic Emission Factors From A Long Term Tracer Study	Belalcazar et al.	N-Propane in LPG	726	30	1	Along the east sidewalk at around 8 m from the axis of the street	✓	✓	✓	✓	✓
Near-road Multipollutant Profiles: Associations Between Volatile Organic Compounds and a Tracer Gas Surrogate Near a Busy Highway	Barzyk et al.	SF6	2	35	15	Northern edge of roadway - 275 m north of roadway	✓	✓	✓	✓	✓[6]
Vehicle Emissions at Intersections	Bullin, Hinz, Bower	SF6	16	15	9	357 m southwest of intersection - 229 northeast of intersection	✓	N/A	N/A	N/A	N/A
Vehicle Emissions at Intersections	Bullin, Hinz, Bower	SF6	30	15	9	122 m southeast of intersection - 345 m northwest of intersection	✓	N/A	N/A	N/A	N/A
Introduction to the DAPPLE Air Pollution Project	Arnold et al.	SF6, PMCH	2	30	10	Within and adjacent to the roadway	Pending	Pending	Pending	Pending	Pending
Short-range Urban Dispersion Experiments Using Fixed and Moving Sources	Shallcross et al.	PMCH, PMCP	2	8	12	Within the roadway and in the surrounding roadways	Pending	Pending	Pending	Pending	Pending

Reference[1]		Tracer Description					Data Acquired				
Article Title	**Author(s)**	**Gas**	**Release Intervals (#)**	**Time of Release Interval (minutes)**	**Measurement Locations (#)[2]**	**Range of Distances from Measurement Locations to Facility (m)[3]**	**Tracer Concentration**	**Meteorology**	**Traffic Volume**	**Traffic Speed**	**Vehicle Type**
Short-range Urban Dispersion Experiments Using Fixed and Moving Sources	Shallcross et al.	PMCH, PMCP	2	8	14	Along the western side of the roadway with a parallel set one street lengths south of Marylebone Road	Pending	Pending	Pending	Pending	Pending
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon[7]	Okamoto et al.	CO	Unknown	Unknown	40	Not quantitatively measured but displayed in Figure 1 in article	No Attempt	No Attempt	Not Measured	Not Measured	Not Measured
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon[7]	Okamoto et al.	NOx, SF6	40	60	15	Not quantitatively measured but displayed in Figure 1 in article	No Attempt	No Attempt	Not Measured	Not Measured	Not Measured
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon[7]	Okamoto et al.	NOx	Unknown	Unknown	Not stated but displayed in Figure 1 in article	Not quantitatively measured but displayed in Figure 1 in article	No Attempt	No Attempt	Not Measured	Not Measured	Not Measured
CityFlux Perfluorocarbon Tracer Experiments	Petersson et al.	PMCH, PMCP	1	10	10	Not quantitatively measured but displayed in Figure 1 in article	No Attempt	No Attempt	Not Measured	Not Measured	Not Measured

Reference[1]		Tracer Description					Data Acquired				
Article Title	Author(s)	Gas	Release Intervals (#)	Time of Release Interval (minutes)	Measurement Locations (#)[2]	Range of Distances from Measurement Locations to Facility (m)[3]	Tracer Concentration	Meteorology	Traffic Volume	Traffic Speed	Vehicle Type
CityFlux Perfluorocarbon Tracer Experiments	Petersson et al.	PMCH, PMCP	3	8	12	Not quantitatively measured but displayed in Figure 2 in article	No Attempt	No Attempt	Not Measured	Not Measured	Not Measured

CO = carbon monoxide, F13B1 = bromotrifluoromethane, LPG = liquid petroleum gas, m = meters, N/A = non-applicable, NOx = nitrogen oxides, PMCH = perfluoromethylcyclohexane, PMCP = perfluoromethylcyclopentane, SF6 = sulfur hexafluoride

[1] Note that in some instances the same reference is cited for multiple tracer experiment datasets. This is because some articles discuss multiple experiments that occurred on different dates and/or locations.

[2] If two or more instruments were placed at the same location but at different heights, then each instrument is counted as a separate location.

[3] Note that experiments measured the distance from the instrument locations to different fixed points of the roadway—the roadway edge, the intersection, the median of the roadway, etc.

[4] ✓ indicates that the dataset acquired

[5] This article summarizes details of a tracer experiment that the author used for their model verification.

[6] Measure of vehicle type was limited to identification of cars and trucks.

[7] This article summarizes details of three different tracer experiments that the authors used for their model verification. The authors of the article did not conduct the tracer experiments.

Table 3-7: Total Number of Different Facility Types

Reference[1]							Number of Facility Types					
Article Title	Author(s)	Year	Journal or Sponsoring Organization(s)	Journal Volume: Issue No.	Page No.	DOI or Report Number	Intersections	Arterials	Freeways	Interchanges	Skewed Intersections	Truck and Bus Terminals
The Mammoth Lake Route 203 Transportation Project: A Case Study in Air Quality Modeling and Mitigation	Benson, Nokes, Cramer	1985	FHWA, Caltrans	N/A	N/A	FHWA/CA/TL-85/11	1	1	1			
General Motors Sulfate Dispersion Experiment: Experimental Procedures and Results	Cadle et al.	1977	Journal of the Air Pollution Control Association	27:1	33-38	10.1080/ 00022470. 1977. 10470389			1			
Analyses, Experimental Studies, and Evaluations of Control Measures for Air Flow and Air Quality on and Near Highways	Dabberdt et al.	1981	FHWA	N/A	N/A	FHWA/RD-81/051			3	1		
CALINE4 - A Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways[5]	Benson	1984	FHWA, Caltrans	N/A	N/A	FHWA/CA/TL-84/15			1			
Intersection Air Quality Modeling	Carr, Johnson, Ireson	2002	NCHRP	N/A	N/A	SYSAPP-02/075d	3					
Vehicle Emissions at Intersections	Bullin, Hinz, Bower	1983	FHWA, Texas A&M University, Texas DOT	N/A	N/A	FHWA/TX-83/14_250_2F	1				1	
Estimation Of Road Traffic Emission Factors From A Long Term Tracer Study	Belalcazar et al.	2009	Atmospheric Environment	:43	5830-5837	10.1016/j.atmosenv. 2009.07.059		1				
Introduction to the DAPPLE Air Pollution Project	Arnold et al.	2004	Science of the Total Environment	:332	139-153	10.1016/j.scitotenv. 2004.04.020	1	1				

Reference[1]							Number of Facility Types					
Article Title	**Author(s)**	**Year**	**Journal or Sponsoring Organization(s)**	**Journal Volume: Issue No.**	**Page No.**	**DOI or Report Number**	**Intersections**	**Arterials**	**Freeways**	**Interchanges**	**Skewed Intersections**	**Truck and Bus Terminals**
Short-range Urban Dispersion Experiments Using Fixed and Moving Sources	Shallcross et al.	2009	Atmospheric Science Letters	:10	59-65	10.1002/asl.211	2	2				
Near-road Multipollutant Profiles: Associations Between Volatile Organic Compounds and a Tracer Gas Surrogate Near a Busy Highway	Barzyk et al.	2012	Journal of the Air & Waste Management Association	62:5	594-603	10.1080/ 10473289.2012. 656819			1			
Evaluation of a Two-dimensional Numerical Model for Air Quality Simulation in a Street Canyon[4]	Okamoto et al.	1996	Atmospheric Environment	30:23	3909-3915	1352-2310/96		3				
CityFlux Perfluorocarbon Tracer Experiments	Petersson et al.	2010	Atmospheric Chemistry and Physics	:10	5991-5997	10.5194/acp-10-5991-2010	2	2				
						Total	10	10	7	1	1	0

Caltrans = California Department of Transportation, DOT = Department of Transportation, FHWA = Federal Highway Administration, NCHRP = National Cooperative Highway Research Program

[1] In some instances, the same article is cited for multiple tracer experiment datasets. This is because some articles discuss multiple experiments that occurred on different dates and/or locations.

Table 3-8: Summary of Wind Tunnel Studies

Reference			Project Details
Article Title	**Author(s)**	**Publication Date**	
Numerical and Experimental Simulation of Vehicle Exhaust-Gas Dispersion for Complex Urban Roadways and their Surroundings	Moriguchi and Uehara	1993	• Simulated a variety of roadway and surrounding configurations, plus a street canyon • Ethane (C_2H_6) used as tracer gas • 28 measurement locations • 15-minute measurement intervals
Concentration Fields at Urban Intersections - Fluid Modeling Studies	Hoydysh and Dabberdt	1994	• Simulated urban arterial/intersection • Ethylene (C2H4) used as tracer gas • Eight measurement locations
Pollution Dispersion At Complex Street Configurations: Covered Roadways	Dabberdt, Hoydysh, and Read	1998	• Conducted in an environmental boundary-layer wind tunnel
Wind-Tunnel Study of Concentration Fields in Street Canyons	Kastner-Klein and Plate	1999	• Simulated street canyon
Heterogeneous Traffic Induced Effects On Vertical Dispersion Parameter in the Near Field Of Roadways - A Wind Tunnel Study	Khare et al.	2002	• Experiment tested the effect of varying traffic volume speed, terrain conditions, and wind direction on vertical dispersion
Effects Of The Homogeneous Traffic On Vertical Dispersion Parameter In The Near Field Of Roadways - A Wind Tunnel Study	Khare et al.	2005	• Simulated a two-lane urban arterial
A Wind Tunnel Study of the Effect of Roadway Configurations on the Dispersion of Traffic-Related Pollution	Heist, Perry, and Brixey	2009	• Simulated a six-lane freeway at 12 different configurations • Experiment tested the effect of different roadway configurations, including noise barriers and roadway elevation or depression relative to the surrounding terrain, on the dispersion of traffic-related pollutants for winds perpendicular to the roadway

Reference			Project Details
Article Title	Author(s)	Publication Date	
Experimental Simulation on Vehicle Emission Dispersion in Urban Street Intersections	Yassin, Kellnerova, and Janour	2009	• Simulated an urban street canyon • Three street configurations of regular-shaped, T-shaped, and skew-shaped intersections
Tracer Flux Balance at an Urban Canyon Intersection	Carpentieri and Robins	2010	• Replicate the conditions at the intersection of Marylebone Road and Gloucester Place in Central London, UK • Gloucester place is three lanes, one-way northbound. The road intersects perpendicularly and Marylebone Road runs approximately from west-south-west to east-north-east. • Conducted at a boundary layer wind tunnel of the Environmental Flow Research Centre at the University of Surrey, UK
Dispersion Modeling Approaches for Near Road	Heist et al.	2014	• Testing for roadside barrier (sound wall)
Effects of Solid Barriers on Dispersion of Roadway Emissions	Schulte et al.	2014	• Testing different barrier heights on concentration during neutral, stable, and unstable conditions

3.2. Historical Ambient Air Monitoring Datasets

We reviewed several existing monitoring databases to assess those that are suitable for use in later model evaluation studies under this project. We focused on current and recent continuous near road monitors, special cases of these near road monitors operated by our cooperating agencies, and with enhanced or well-studied data, FHWA and EPA National Near-Road Studies, and other near road studies. While many of these datasets present problems for model comparisons due to uncertainties introduced in their real-world, uncontrolled conditions, they are more widely available and potentially cover a broader range of facility types. The following describes our findings from each of the four study types.

3.2.1. Existing Monitor Datasets

The first existing database we explored was EPA's near road monitor database.[3] EPA maintains this list of ambient air pollution monitoring stations in the near-road environment. The sites in this "near-road monitoring network" were established as part of the 2010 NO_2 NAAQS review, and was most recently updated in May of 2017. EPA cooperates with state, local, and tribal air agencies in installation and maintaining data from these near-road NO_2 monitoring stations across the country.

Many of these sites monitor multiple pollutants, including carbon monoxide (CO) and particulate matter (PM). We are interested in CO and PM datasets, as they are modeled for project-level air quality analyses. Of those, CO is the highest priority as it is most suitable for evaluating air dispersion models due to it being nearly inert. $PM_{2.5}$ and NO_2 may also be considered, but both have modeling complications due to high background concentration and the variety of emissions processes for PM and the complex photochemistry of NO_2. Black carbon particulate (BC) is also measured in some cases, and also inert, but may be difficult to reconcile between emissions models and observed values.

Some 80 sites are listed in this dataset. We filtered those to 15 potential sites based on the provided metadata including sites that record the pollutants of interest (CO and PM) and have on-site meteorological data. We then sorted these 15 sites into three "tiers", considering the following elements:

- the types of measurements for these regulated air pollutants,
- whether measured background concentrations are available to isolate facility contributions,
- whether coincidental traffic counts are available (note that all have reported average daily traffic, AADT),
- sufficiently high traffic volumes and lack of other significant local sources that could influence concentration signal from the target roadway relative to background, and

[3] This dataset is available as a spreadsheet from US EPA, at: https://www3.epa.gov/ttnamti1/files/nearroad/Near-road%20Monitoring%20Network%20Site%20List%20-%20May%202017.xlsx.

- the types of transportation facilities that could also be considered from adjacent secondary roads, beyond the measurement's target roadway.

We found no sites that we considered "Tier 1", or ideal candidates for modeling (all elements were satisfied). We found ten sites we considered "Tier 2", cases that had strong elements (at least 3 of the 5 elements), but mitigating issues. The remaining five we considered "Tier 3", or those unlikely to serve our purposes.

All fifteen sites monitored CO. All monitored PM, although some had continuous measurements, some gravitational, and some both. Some also measured black carbon particulate. As far as we can tell, none of these sites reported that nearby monitors could be used to provide background concentrations. Sites, were considered higher Tier if their configuration or traffic level was high enough to lend itself to higher signal from the roadway relative to other nearby sources. All fifteen selected sites had on-site meteorological observations.

All sites targeted freeways, although some hold promise for potential interchange facility analysis. Many could potentially be influenced by adjacent major or minor arterials, or bus and train facilities. Table 3-9 summarizes the ten Tier 2 sites.

Table 3-9: Near-Road Ambient Monitoring Sites

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Hartford-West Hartford-East Hartford, CT	41.771423, -72.679982	Interchange (I84 at High St Onramp)	Major arterial, overpass, onramp. Near end of small rail line.	Urban	Yes	Nearby bus station. Potential SNR issues but also potential for interchange evaluation.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Baltimore-Columbia-Towson, MD	39.143092, -76.846078	Freeway (I95)	Truck/rest stop. Major arterial about 2,000 ft SW.	Rural/suburban. Expect only minor truck stop influence.	no	At a highway rest stop, surrounded by wooded area. Expect good signal. No direct traffic counts.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Denver-Aurora-Lakewood, CO	39.73215, -105.01526	Freeway (I25)	Only minor other roads nearby. Hwy 6 about 1,000 ft S.	Urban	No	Central, urban location. Expect good signal. No direct traffic counts.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Seattle-Tacoma-Bellevue, WA	47.597481, -122.319858	Interchange / Freeway (I-5)	1,000 ft from I-90, but adjacent to interchange on ramps. Other urban minor arterials nearby.	Urban	No	No direct traffic counts. Expect good signal.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Tampa-St. Petersburg-Clearwater, FL	27.955546, -82.467241	Freeway (I-275)	Major arterial underpass (North Blvd)	Urban	No	Under/next to a highway overpass. Good setting. No direct traffic counts. Expect good signal.

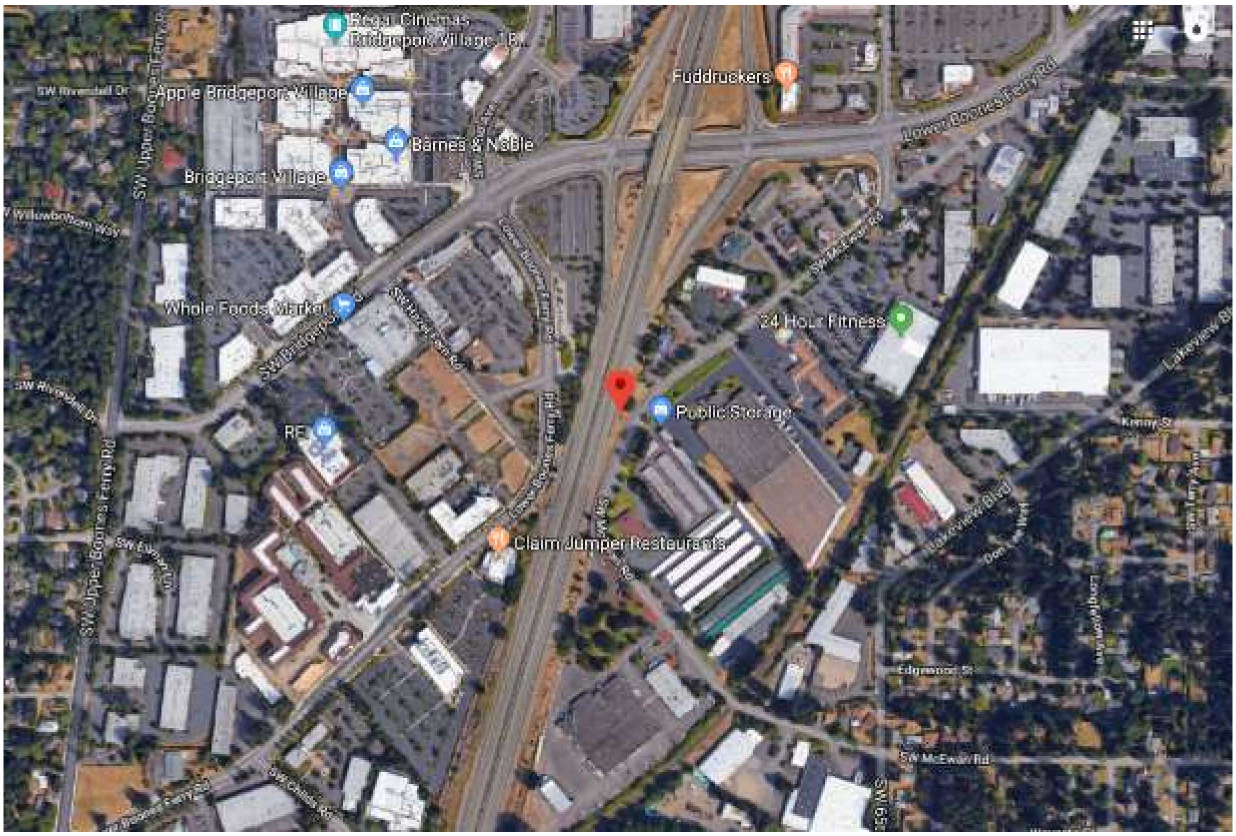
Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	St. Louis, MO-IL	38.631057, -90.281144	Freeway (I-64)	Interchange/Major arterial (but downstream enough to focus on freeway - 1500' to interchange and opposite side of frwy from and at end of on-ramp)	Urban (but in large park)	No	In a large park Adjacent to the highway. No direct traffic counts. Expect good signal.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	40.053856, -74.985839	Freeway (I-95)	None, but adjacent to commuter rail	Suburban	No	Freeway setting but compromised by adjacent rail station and lines. No direct traffic counts.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Kansas City, MO-KS	39.047911, -94.450513	Freeway (I-70)	Interchange/Major arterial, but opposite side of freeway from and at end of off-ramp. 1,000 ft from on ramp.	Suburban	No	Freeway setting. No direct traffic counts. Expect good signal.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Charlotte-Concord-Gastonia, NC-SC	35.213171, -80.874084	Freeway (I-77)	Interchange/Minor arterial, but opposite side of arterial and 600 ft from on ramp.	Suburban	No	Freeway setting. No direct traffic counts. Expect good signal.

Tier	CBSA Name	Monitor Site (Latitude, Longitude)	Target Road Type	Secondary Road Types	Setting	Coincident Traffic Counter?	Other Notes
2	Portland-Vancouver-Hillsboro, OR-WA	45.393497, -122.747894	Interchange / Freeway (I-5)	1,000 ft from interchange but at end of ramps. On off-ramp side.	Suburban	No	Potential interchange setting. No direct traffic counts. Potential influence from adjacent sources.



3.2.1.1. FHWA Pooled Near Road Research

The FHWA and participating states engaged Sonoma Technology, Inc. (STI) to conduct an analysis of national results from the near road studies noted above. This work was completed as part of the Near-Road Air Quality Research Transportation Pooled Fund, TPF-5(284). STI has published three reports summarizing their findings on U.S. near-road pollutant concentrations, with the most recent focusing on data from year 2016.[4]

[4] National Near-Road Data Assessment: Report No. 3, With 2016 Data, Final Report. Prepared for Washington State Department of Transportation by STI under for the Near-Road Air Quality Research Transportation Pooled Fund, TPF-5(284), February 2018.

The pooled near road studies provide detailed analysis of results at the national scale. This is not directly related to modeling individual near road sites for this modeling performance study, but information in this analysis can guide site selection. For example, the "Single Upwind Site" approach used to compute $PM_{2.5}$ increment can help identify sites where a reasonable background value could be approximated from other nearby monitors. Based on STI's 2016 analysis, only a single site identified above also meets the qualifications for the single upwind site for $PM_{2.5}$ – the Denver-Aurora-Lakewood, CO, site (AQS ID 08-031-0027). However, a similar analysis to what STI did for PM would need to be done for other pollutants before using this approach to identify sites for modeling.

3.2.2. Special Near-Road Monitor Datasets

In addition to the basic sites described in Section 3.2.1, two of our cooperative agencies have conducted additional studies. These are described below:

3.2.2.1. 10th Ave. S. and Weller St., Seattle, WA

This permanent near-road monitor site is the same Seattle site shown in Table 3-9, above. The Washington Department of Ecology (Ecology) has been involved in analyses based on observations from this site. Ecology has collected $PM_{2.5}$ speciation data here over several years. Ecology has as well datasets of $PM_{2.5}$,black carbon, CO, NO_2, NO, NOx, and meteorological data, available from EPA's Air Quality System. In addition, Ecology staff is currently conducting a source apportionment study of the speciation data. Ecology expects this analysis to be complete by the December 2018 and will share the study with the Research Team when it becomes available. Such apportionment data could assist a modeling study, but would be complicated by multiple modeling steps that would need to be aligned, along with the complications regarding $PM_{2.5}$ noted earlier.

In addition to Ecology, the Puget Sound Clean Air Agency (PSCAA) has recently completed an EPA-funded air toxics monitoring study that included the 10th and Weller observations as the principal element. This was based on one year of site sampling, from Fall 2016 to Fall 2017. The documentation of this study is available from PSCAA;[5] the dataset is available from EPA's Air Quality System. Notably, this study includes an air quality dispersion model (AERMOD) and PMF analyses of the highway vehicle emissions on I-5 and I-90, and adjacent sources (restaurants) in the study area. While neither PSCAA nor Ecology used hourly traffic information explicitly in their analysis the site is located 0.33 miles from a permanent traffic counter on I-90 along with an array of traffic counts collected in the nearby vicinity. These are available from WSDOT Traffic GeoPortal.[6]

3.2.2.2. I-25/I-70 Interchange, Denver, CO

At the Denver site shown in Table 3-9, the Colorado Department of Public Health and Environment (CDPHE) and the City and County of Denver have been involved in an air toxic

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[5] Available at http://www.pscleanair.org/DocumentCenter/View/3398/Air-Toxics-Study-in-the-Chinatown-International-District-Full-Report.

[6] Available at: http://www.wsdot.wa.gov/data/tools/geoportal/?config=traffic&layers=2

gradient study near the I-25/I-70 interchange.[7,8] This study shows promise as a specifically interchange setting. However, use of air toxics – the focus of this study – could complicate the dataset for use as a model validation study.

This study is ongoing. The study has been delayed, due to sampling issues, but they continue to follow the original proposed approach. Colorado DPHE reports that the study is expected to be completed by the end of December, 2018.

3.2.3. FHWA and EPA National Near-Road Studies: Las Vegas and Detroit

FHWA and EPA collaborated with Nevada and Michigan DOT's on research projects to characterize near-road PM and mobile source air toxic (MSAT) impacts near highways. Two special datasets were collected as part of this research effort. The first dataset was collected in Las Vegas, NV from December 2008 to December 2009.[9] The second was collected in Detroit, MI, from mid-2010 through June 2011.[10] Both datasets contain traffic count, vehicle type, and speed data along with ambient measurements of pollutants, including CO, NOX, and $PM_{2.5}$[11] and meteorological conditions.

FHWA and EPA are still processing, performing analysis with, and quality assuring these datasets. Currently, EPA is focusing its attention on a more "polished" and limited subset of the data for detailed modeling. This "polishing" is particularly focused on addressing past issues with the traffic data in the Las Vegas dataset. EPA indicated they would have their final version of this data within about 4 months and, because this process is still ongoing, would prefer waiting until finalized before sharing.[12]

Both datasets are potentially suitable for project-level model inter-comparison study. Both are freeway studies, with on-site meteorological measurements and background concentrations have been made to try to isolate the freeway contribution as well as trying to measure the downwind concentration gradient. However, the Detroit dataset was used in developing the parametrizations for the dispersion coefficients in the RLINE dispersion model. This would make this dataset biased for modeling done with RLINE and is therefore not recommended for the model inter-comparison study if RLINE is evaluated as part of that inter-comparison.

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[7] https://www3.epa.gov/ttnamti1/files/2015csatam/ColoradoProjectNarrative.pdf

[8] https://www.colorado.gov/pacific/sites/default/files/051718_Globeville-presentation_APCD.pdf

[9] **FHWA and EPA National Near-Road Study: Las Vegas**, EPA IAG: RW-69-922499, FHWA IAG: DTFH61-07-X-30015, Period of Performance: June 1, 2007 to September 30, 2010, Project Officer: Daniel A. Vallero, U.S. Environmental Protection Agency MD E-205-02 109 TW Alexander Dr. Research Triangle Park, NC 27711.

[10] **FHWA and EPA National Near-Road Study Detroit**, EPA IAG: RW-69-922499, EPA IAG: RW-69-923285, FHWA IAG: DTFH61-07-X-30015, FHWA IAG: DTFH61-10-X-30037, Period of Performance: June 1, 2007 to September 30, 2011, Project Officer: Daniel A. Vallero, U.S. Environmental Protection Agency, MD E-205-02, 109 TW Alexander Dr., Research Triangle Park, NC 27711.

[11] MSATs were a primary focus of the studies along with other pollutants. We are interested in PM, CO, and possibly NO2 for this study.

[12] Personal communication with Chris Owen and Sue Kimbrough, EPA, and Victoria Martinez, FHWA, October 3, 2018.

3.2.3.1. Las Vegas

Air quality data was collected from a roadway site at the south end of the Las Vegas strip just north of Sunset Road from four different sensors arranged perpendicular to I-15, which averages over 200,000 vehicles per day (Figure 3-1). The sensors were positioned at 10, 100, and 300 meters in the prevailing downwind direction with one sensor 100 meters typically upwind. The site is located at a section of roadway at slightly depressed elevation relative to its surroundings, and is also near a railway and truck staging yard. Data consistency and quality issues have been of particular concern for the measurements of $PM_{2.5}$, especially, as well as issues in traffic characterization. EPA is still working on addressing issues in this data. However, data is considered much more reliable for CO.

Figure 3-1: Las Vegas Study Near Road Study Configuration

Source: FHWA and EPA National Near-Road Study: Las Vegas, Figure 1. (Footnote 9)

3.2.3.2. Detroit

Air quality data was collected from a roadway site in downtown Detroit adjacent to I-96. The site had four different sensors arranged roughly perpendicular to the roadway at 10, 100, and 300 meters downwind, and 100 meters upwind (Figure 3-2). The site has annual average daily traffic of roughly 165,000.

Figure 3-2: Detroit Study Configuration

Source: Figure 1 FHWA and EPA National Near-Road Study Detroit (Footnote 10)

3.2.4. Other Studies

3.2.4.1. Watt Road

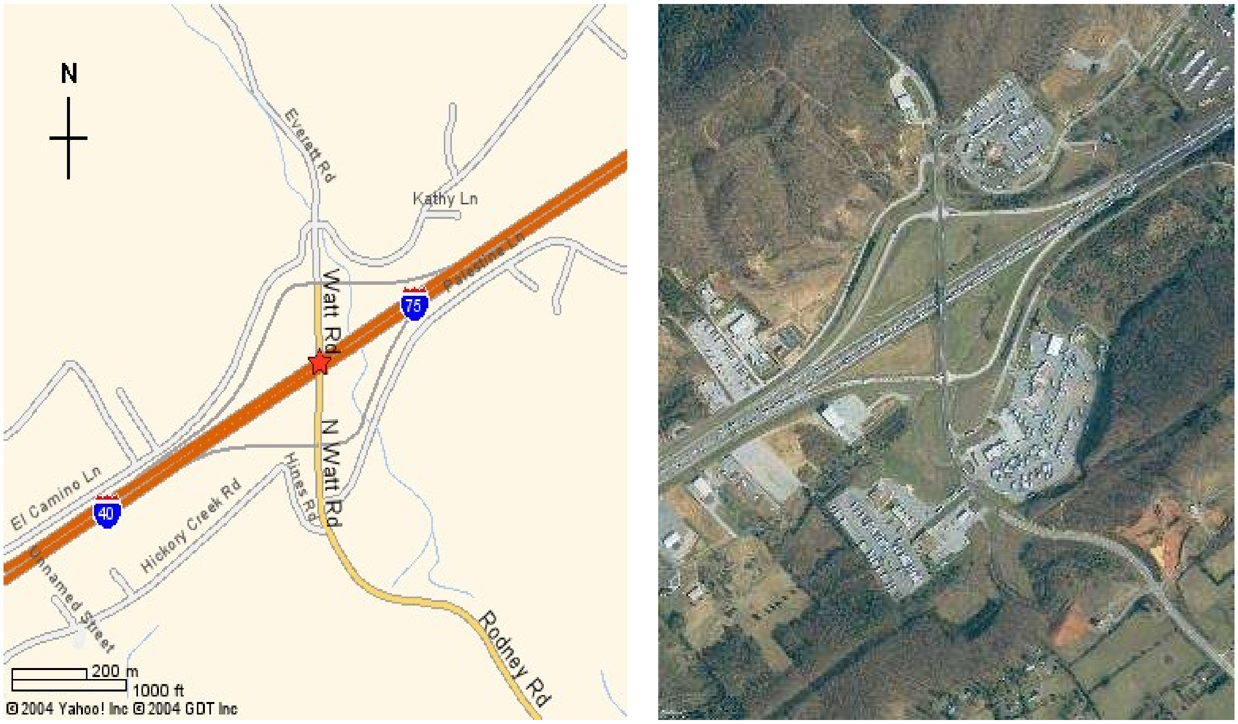
The University of Tennessee-Knoxville (UTK) completed a study on the impact of heavy heavy-duty diesel truck (HHDDT) idling emissions at a truck-stop facility outside of Knoxville, TN, aimed at assessing the effectiveness of a specific idling reduction technology (Indale, 2005).[13] The study included monitoring and modeling of PM and NOx emitted by vehicles at truck travel centers and nearby freeways of the Watt Road Interchange, where the combined I-40 and I-75 interstates pass under Watt Road (Figure 3-3).

There were three large travel centers built around this interchange: a Petro, a TA, and a Flying J facility, with a combined overnight HHDDT parking capacity of about 700 spaces. The UTK group installed two trailers in the parking area of the Petro Travel Center (the largest facility shown in the southeast quadrant in Figure 3-3) with facilities to continuously monitor ambient concentrations of $PM_{2.5}$, NOx, and CO. A meteorological monitoring station was located in the median of the southwest corner of the I-40/Watt Road interchange and measured temperature, air

[13] Indale, G.T., 2005. Effects of Heavy-Duty Diesel Vehicle Idling Emissions on Ambient Air Quality at a Truck Travel Center and Air Quality Benefits Associated with Advanced Truck Stop Electrification Technology, Doctor of Philosophy Dissertation, Department of Civil Engineering, University of Tennessee, Knoxville, May 2005.

pressure, rainfall, wind speed, wind direction, the standard deviation of wind direction (σ_θ), relative humidity, and solar radiation. Measurements were taken from December 2003 to August 2004. Indale and, later, ICF[14] modeled this area with both ISCST3 and AERMOD.

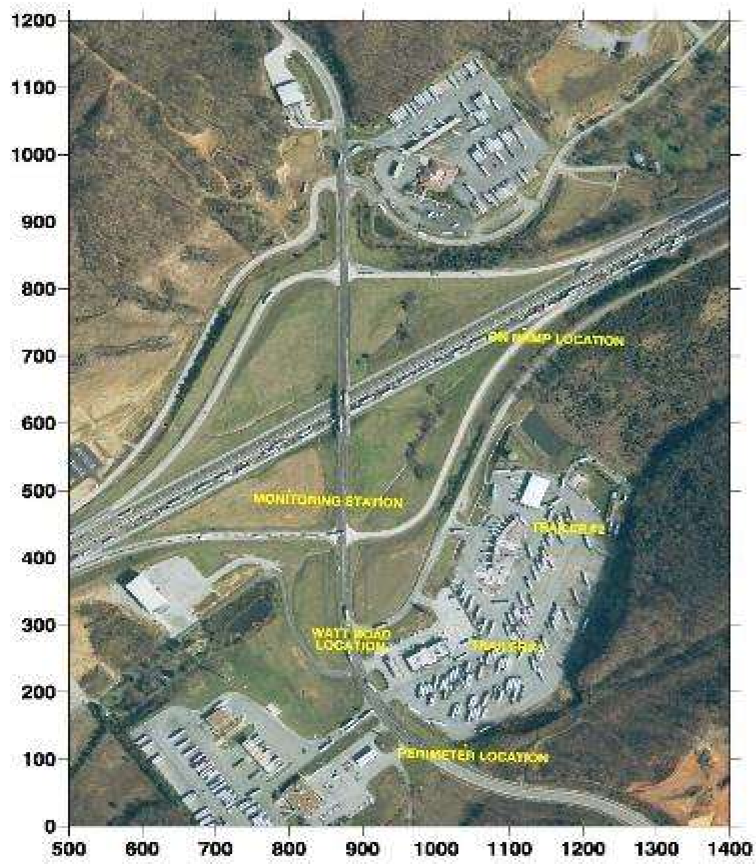
Figure 3-3: Map and Aerial Photo of the Region of the Watt Road Study



Although this study's original focus was on truck stop idling, multiple sources were characterized in the modeling and observed values, including the freeway, overcrossing arterial, ramps, in addition to the truck stops. During the study, Oak Ridge National Laboratory conducted an intensive two-week monitoring period focused on freeway emissions. however, Indale's and ICF's modeling both concluded that pollutant concentrations at the monitoring facilities, as well as at other key locations throughout the modeling domain, were influenced by traffic along the freeways, Watt Road, and the Ramps, but typically dominated by emissions at the truck stops, primarily from local idling HDDVs. ICF's modeling showed the non-truck stop contribution to period-average concentrations at the six locations shown in Figure 3-4 ranged from about 10 % at the Perimeter and Trailer 1 locations, to about 20 % at Trailer 2, to 30 % at the Watt Road location. Even receptor locations focused on contributions from other sources (at the Monitoring Station and On Ramp locations) showed period-average contributions of only about 50 % from non-truck stop sources.

[14] Hartley, W. Seth, Edward L. Carr, and Chad R. Bailey, 2006. "Modeling Hotspot Transportation-Related Air Quality Impacts Using ISC, AERMOD, and HYROAD". Presented at the "Guideline on Air Quality Models: Applications and FLAG Developments" AWMA Specialty Conference, Denver, CO, April 26-28, 2006.

Figure 3-4: Location of Selected Receptors



Given the moderate fractional contribution from roadways to observed concentrations, we do not recommend the Watt Road Study as a possible dataset for highway or interchange analyses.

3.3. Recommendations for Historical Ambient Air Monitoring Datasets and Additional Tracer Experiments

We have identified historical ambient monitoring datasets suitable for the model inter-comparison study based on having nearby measured background concentrations to isolate facility contributions, have on-site meteorological data, and have sufficiently high traffic volumes to create a strong signal relative to background. These sites also have measurements of traffic volume nearby and have high quality continuous CO and $PM_{2.5}$ measurements. These are discussed in Section 3.3.1.

We have also identified tracer datasets that have been collected in the near roadway environment that have measured not only the tracer gas, but have also collected information on: traffic, meteorological, facility design layout (geometry) and project environmental setting. In Section 3.3.2 we provide recommendations on the set of tracer studies to be undertaken in Task 4 and 6 and the set of historical tracer studies suitable for the model inter-comparison study.

3.3.1. Historical Datasets

Based on the review of the historical datasets we have identified three ambient air monitor sites that would be suitable in the model inter-comparison study.

The ambient air monitor in the Baltimore-Columbia-Towson, MD is expected to have a good signal to noise ratio, with the freeway contribution only partially influenced by other sources, including the rest stop itself. Continuous measurements of $PM_{2.5}$ are made along with CO, NO_2, and air toxics. Maryland DOT has sample vehicle counts at the entrance to both the north and south bound entrances to the rest stop, and along the target road (I-95) roughly 0.8 miles south of the monitor site.[15] These sites should provide a reasonable estimate of the diurnal profile and an indication of other activity that influences the monitor (rest area exit and entry).

A second possibility is the 10th Avenue South and Weller Street site in Seattle, WA. The Seattle site collects measurements of $PM_{2.5}$ in addition to observations of CO, NO_2, and black carbon. This site has also been used extensively in other local studies, including by our cooperating agency.[16] The site is located 0.33 miles from a permanent traffic counter on I-90 along with an array of traffic counts collected in the nearby vicinity. These are available from WSDOT Traffic GeoPortal.[17]

A third suitable dataset is the Las Vegas Near-Road study for consideration. However, as noted it suffers from data consistency and quality assurance issues especially for the traffic data. However, EPA is working to improve characterization of the traffic data and anticipates the dataset to be available within the next four months. Also, the age of the dataset (~ 10 years old) maybe at issue as vehicle emission technology has changed in the intervening years.

Table 3-10: Summary of the Historical Ambient Air Monitoring Datasets for Consideration in the Model Inter-comparison Study.

Site Name	Best Match Facility Type	Database	Qualifiers
Columbia, MD	Freeway	EPA near road monitor dataset	Pending characterization of activity at rest area
Seattle, WA	Freeway	EPA near road monitor and special case study datasets	Potentially also representing an interchange facility
Las Vegas, NV	Freeway	FHWA and EPA National Near-Road Studies	Pending EPA-provided; clean dataset; Dataset is ten years old

15 I-95-0.50 Mi north of MD216 (latest data from 2015) available at: http://maps.roads.maryland.gov/itms_public/?stationID=B2530. I- 95I - Entrance to I- 95 South Welcome Center (latest data from 2017) available at: http://maps.roads.maryland.gov/itms_public/?stationID=S2008130002. I- 95K - Entrance to I- 95 North Welcome Center (latest data from 2015) available at: http://maps.roads.maryland.gov/itms_public/?stationID=S2008130001. Other potentially useful traffic data available from MDOT at: https://www.roads.maryland.gov/Index.aspx?PageId=251.

16 PSCAA recently completed an air toxics monitoring study including 10th and Weller with sampling from fall 2016 to fall 2017, available at: http://www.pscleanair.org/DocumentCenter/View/3398/Air-Toxics-Study-in-the-Chinatown-International-District-Full-Report. Washington Department of Ecology has also collected $PM_{2.5}$ speciation data at 10th and Weller for several years, with data available from EPA's AQS system.

17 Available at: http://www.wsdot.wa.gov/data/tools/geoportal/?config=traffic&layers=2

3.3.2. Recommend New Tracer Studies and Suitable Historical Tracer Datasets

Review of Table 3-7 shows that interchanges, skewed intersection and truck and bus terminals have had few or no tracer experiment studies. We therefore recommend that three of the four tracer experiments to be carried out in Task 6 be performed for these three settings. The fourth experiment could be a repeat of one of these settings or alternatively an arterial setting. At the completion of these tracer studies, in combination with the historical tracer studies available for intersections and freeways, a comprehensive dataset for future model evaluation studies will be available.

Historical tracer studies recommended for the model inter-comparison study are summarized in Table 3-11. These tracer studies cover three facility types: freeway, intersection and arterial.

Both the GM sulfate experiment and the Caltrans Highway 99 tracer studies have been widely used in past model comparison studies for freeways. Of these two freeway settings we recommend the GM sulfate experiment due to the much higher traffic volumes that are more typical of volume levels on freeways today. Of the two intersection tracer studies shown in Table 3-11 the Denver intersection reported higher concentrations with slightly higher traffic volumes with a few more receptor locations than the Tucson dataset. However, given that the new tracer experiments are to be carried out in Task 6 will take place in the Northern Front Range of Colorado it may be better to use the Tucson intersection study to increase geographic diversity. Finally, we have included the Ho Chi Minh City tracer study even though it could be viewed as a street canyon study due to the surrounding buildings and trees, but it does represent a typical densely built area up area representative of many urban locations of transportation projects.

Table 3-11: Summary of the Tracer Experiment Datasets for Consideration in the Model Inter-Comparison Study (preferred facility type in bold).

Study Name and Location	Facility Type	Comment
General Motors Sulfate Experiment	**Freeway**	**GM test track Milford, Michigan located in a lightly wooded area with rolling terrain. The experiment used a fleet of vehicles representing 5,462 veh/hr, average speed of 50 mph. The study has been widely used in a number of model evaluation studies.**
Caltrans Highway 99 Tracer Study, Sacramento, CA	Freeway	Rural location along US Hwy 99, with 35,000 AADT, widely used in a number of model evaluation studies
NCHRP 25-6 Tracer Study – Denver, CO	Intersection	Suburban location at the intersection of Hampden Ave and University, 99,000 AADT
NCHRP 25-6 Tracer Study – Tucson, AZ	**Intersection**	**Suburban location at the intersection of 22nd and Alvernon, 82,000 AADT**
Ba Thang Hai street , Ho Chi Minh City, Vietnam	**Arterial**	**3-4 story buildings along both sides of street and 70-85 foot tall trees along the avenue. 12,000 AADT (not including motorcycles) 30-days of tracer experiments (daytime)**

3.3.3. Datasets for Model Inter-Comparison Study

Based on the resources available to perform the model inter-comparison study and the number of air quality dispersion models needing to be run (4) for each monitoring dataset we estimate that a **total of three complete datasets with all 4 models can be analyzed in Task 7.**

We recommend that two of the datasets come from the tracer datasets that we identified in Section 3.3.2 (either one from the tracer experiments to be carried out in this research and one historical tracer study or both from the historical tracer study). To provide the most robust comparison of the air quality models range of capabilities (not encumbered with the uncertainty with the vehicle emissions) the third dataset should also come from the historical dataset. Table 3-11 summarizes our recommendations on the three datasets to use in the model inter-comparison study.

Table 3-12: Recommend Datasets for Model Inter-Comparison Study

Study Name and Location	Facility Type	Comment
General Motors Sulfate Experiment (Tracer Study) Milford, Michigan.	Freeway	Fairly high freeway traffic volume dataset that has been used in a number of past model comparison studies.
NCHRP 25-6 Tracer Study – Tucson, AZ	Intersection	Suburban location at the intersection of 22nd and Alvernon, 82,000 AADT – tracer monitored at many locations about the intersection
NCHRP 25-55, Tracer Experiment - Northern Front Range of Colorado	Interchange	Could build on lessons learned from CDPHE from the I-25/I-70 interchange. Experiment too be carried out in Task 6.

Alternatively, the third dataset could be from the historical ambient air monitoring datasets from the three studies identified in Table 3-10 if less controlled and broader study is desired. Here we would recommend the Columbia, MD freeway dataset to provide additional geographic diversity in lieu of the GM sulfate experiment.

4. OUTLINE OF MODEL IMPROVEMENT PROGRAM

We have developed a draft outline of a Model Improvement Program (MIP) specifically designed for air quality analysis of transportation projects. The draft outline incorporates the most relevant findings from the:

- 2007 National Research Council "Models in Environmental Regulatory Decision Making" The National Academies Press. https://doi.org/10.17226/11972 in particular the findings related to a model evaluation plan, the peer review process and model parsimony.

- EPA Inspector General Report: "EPA Can Strengthen Its Process for Revising Air Quality Dispersion Models that Predict Impact of Pollutant Emissions", Report No.18-P-0241, September 2018, in particular the findings related to documentation of model revisions

The MIP is designed to be a generic process, in that it does not assume one particular model to be considered (e.g. AERMOD). It does assume use of an atmospheric dispersion model, simulating atmospheric processes. The outline also assumes that the MIP will be applied to an existing model being applied in a transportation setting, rather than a model being developed from first principles, which would significantly extend the MIP in duration and complexity.

The draft outline for the MIP does not consider any specific procedural use of the model (i.e. transportation conformity, NEPA, and/or state environmental requirements). The MIP could be used in the context of existing or potential future air pollutant that requires a microscale analysis to determine a pollutant concentration (the draft outline lists some potential future pollutants).

The draft outline should be applied to revisions of air quality dispersion models that affect the outcome of the model (such as estimated pollutant concentrations). It suggests a repository of the model's history that would be used to document minor revisions to the model that do not affect the results of the model.

Although focused on transportation projects, the MIP can be used by any agency needing to perform an air quality analysis for a transportation project or for a project that could affect traffic levels and operations on nearby roadways and, thus, affect air quality. It is not limited to State DOT projects. It is assumed that the any analyst performing the modeling effort within the context of the MIP is well versed in air quality dispersion modeling and fully technically capable of running and applying the air quality model in question.

The draft outline assumes that the modeling is performed at the microscale (tens of meters horizontal resolution up to hundreds of meters) analysis. It does not anticipate the use of the MIP for air quality analyses that may be done on a regional or corridor scale. It also does not consider peripheral air quality analysis that may be done in conjunction with a project-level transportation project air quality analysis (e.g. an analysis of emissions associated with the construction of the project).

Section 3.2 of Appendix W (EPA Guideline on Air Quality Models as published in Code of Federal Register[18]) discusses "Alternative Models" to the models listed in Appendix A of Appendix W and describes a process for allowing use of a model, other than an approved model, if it can be documented that the "alternative" model performs better in the specific case or situation. It is recommended that the MIP, as outlined in the attachment, be considered as a potential method to achieve USEPA regulatory acceptance for an air quality model to be used in a transportation setting, beyond the current, or future, accepted air quality model(s).

[18] The most recent version is published in FR 82, No, 10, pp 5182-5235.

Model Improvement Program Outline

Assumptions:

- The air quality dispersion model will simulate atmospheric processes. It will not be a statistical model (as defined in the NRC report) or a conceptual model (although see discussion below in the peer review element).
- The air quality model will preferred to not be a proprietary model, although interfaces/input-output screens can be.
- The air quality model will not be a new model (from first principles) but a "tested" model.
- Process will be geared towards a technical audience.
- Process can be continued periodically through the use of the model (its life-cycle)
- Process focuses on application of the air quality model for use in transportation project modeling setting, not an overall model evaluation or its use in other settings (e.g., stationary sources)
- This process should be used for revisions to the model that affect its calculations and subsequent results (e.g. changes to the formulation or parameterization of the Monin-Obukhov length). Minor revisions to the model (e.g. corrections to typographical errors for labels in the output of the model) should be documented in the model's history and notification given to interested parties.

1. Define need for implementing the Model Improvement Program (MIP)
   - new model for transportation applications
         - Traditional line source or something new? Combination?
     - transportation project type not adequately considered by existing models
         - Mixed source types, such as road and intermodal facility in the same project area.
     - Strong evidence that existing model(s) get "wrong" answer.
         - e.g. the model generates concentration estimates that are substantially greater or less than observed
     - new NAAQS with microscale component.
         - Which pollutants: conceivably -
             - PM ultrafine particles
             - NO2
             - Air Toxics
   - Elapsed time (e.g. 10 years) to determine if external developments (new science) warrant a re-engagement of the process
     - Considering the life of existing models (>>10 years, sometimes with little or no update), what kind of new science might be anticipated?

    - Specify conditions for when a model should have an "end of life", if possible.
- Determine if process will be by pollutant, transportation project type, and/or other consideration
    - Traditional dispersion models were designed first for inert chemical conditions; CO is the best transportation example.
    - Other pollutants are generally added via adjustments for things like chemistry and deposition.
    - Treatment of different project types may vary the source characteristics rather than the dispersion modeling itself.
    - Are there unique characteristics of some kinds of transportation project that would be better served by some other form of the model?

2. Establish Model Evaluation Plan
    - Documentation of QA/QC procedures
    - Focus evaluation at transportation project application stage of model
    - Avoid unnecessary model complication (model parsimony)
        - One model for everything – current process – minimizes the number of models, but can complicate the choice of model options, and affect computational needs, for different project locations, types of projects, source types, and receptor identification. Does the single model work well enough for all those variations?
        - What specific project or source types would be better analyzed for localized effects using some model formulation other than the standard do-all model?
    - Discuss tradeoffs that affect complexity, transparency, understanding, etc.
    - Include model history
    - Include conceptual version of model in a transportation setting (e.g. flow diagram) for understanding by decision makers, stakeholders, public, other non-technical audience
    - Define uncertainty for the modeling process (lack of knowledge, natural variability, input variability) and how it will be addressed
    - Determine if model will be for screening purposes, detailed analyses or both
    - If evaluating against an existing monitored air quality data base, determine source of database and obtain database
        - Tracer study details
        - Other monitoring analysis details
        - Model development process details
    - Determine needed data and assemble data
    - Determine independence of data (i.e. was data used to develop model)
    - Determine statistical tests and outcomes to define "acceptability" of model in a transportation setting
        - For example, may want to consider more rigorous test than standard unpaired in time and space statistics

3. Establish Peer Review process
    - Determine needed size of committee (suggest 10-15 members)
    - Invite participants (e.g. USDOT, USEPA, state DOTs, state air agencies, AASHTO, academia, etc)
    - Establish roles and responsibilities of committee (Chair, etc.)
    - The Committee will document all its reviews, comments, etc. to ensure a transparent process
    - Establish process/means of communicating uncertainty aspects to interested parties
    - Establish if retrospective analysis should be done to examine need/type of future model improvements for transportation projects
    - Establish need for greater documentation of model for transportation applications (e.g. enhanced user's guide)
    - Specify application of model to transportation project types and range of conditions and use (extrapolation)
    - Determine best methods of communicating results, application, statistical outcome to decision makers, stakeholders, etc.

4. Perform model runs and analyze results
    - Determine traffic inputs from field collection or traffic model
    - Determine geography and facility layout
    - Determine emission inputs from emission factor model (e.g., MOVES) runs
    - Determine sources of background concentration and how background will be assessed in determining model performance
    - Determine meteorological inputs: if screening application, establish worst-case conditions; if detailed analysis application, determine source and type of meteorological data; if nearby met data is not available, determine appropriate methods for estimating or modeling it.
    - Determine number of needed model runs
    - Perform model runs
    - Compile and analyze results
    - Perform statistical tests to determine model performance and establish "acceptability" of model for transportation application
        - Need to establish "right answer" for "right reason" not just for high performance statistics (e.g., paired in time and space statistics)
    - Document if model is not performing acceptably under certain conditions (e.g., not to be used for certain project types because of "poor" performance)
    - Document overall process and results and conclusions