

# Traffic Data for Integrated Project-Level PM<sub>2.5</sub> Conformity Analysis

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| 16. Abstract<br>As required by the U.S. Environmental Protection Agency (EPA), the MOVES model is the mandatory emission tool for new PM hot-spot analyses for project-level conformity determinations that began after December 20, 2012. Localized traffic data inputs to the model are crucial in maximizing its capability to accurately reflect the PM <sub>2.5</sub> emissions associated with transportation programs and projects. However, accurately acquiring local traffic operating related data for project-level MOVES analysis is always a challenge to realistic practices. To address the issue, the three existing traffic data sources in Ohio that can be used as inputs for the MOVES model have been identified and analyzed through the project. The first one is referred to as the ATR data source, which contains hourly or 15-minute traffic volume and vehicle composition. The second one, PVR data source, provides individual vehicle's timestamp, class and speed information. The third one is the micro-simulation data source, which includes individual vehicle's class, speed profile and acceleration profile. The applicability of the available data sources has been evaluated by using the sample data collected on the I-275 freeway in Cincinnati, Ohio. Specifically, the roadside PM <sub>2.5</sub> concentration is estimated based on the sample traffic data and the modeled concentration is compared to the observed data. The compared results indicate that the PVR data source is preferred for the project-level PM <sub>2.5</sub> analysis. It requires less effort to collect and provides the most accurate results when compared to other data sources. The normalized mean-square-error of the modeled concentration can be reduced by 30.5% if the PVR data are used with the operating mode distribution data prepared based on the simulation data source. Finally, an easy-to-use computer tool in the ArcGIS environment, termed as Traffic Air Environmental Health Impact Analysis (TAEHIA) supporting system, has been developed to facilitate the application of the identified data sources into the PM <sub>2.5</sub> conformity analysis conforming to the ODOT and U.S. EPA guidelines. The TAEHIA system is designed to: 1) incorporate the traffic data sources available in Ohio; 2) implement the PM <sub>2.5</sub> conformity analysis steps as recommended by the EPA hot-spot conformity analysis guideline; and 3) simplify users' tasks in the conformity analysis. The application of the TAEHIA system has been demonstrated in two case studies. As shown by the case studies, it is a user-friendly, straightforward way to analyze the transportation conformity within the TAEHIA environment. |   |  |  |
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(State Job Number 134662)

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## LIST OF ACRONYMS

|        |   |
|--------|---|
| AADT   | Average Annual Daily Traffic                              |
| ARB    | California's Air Resource Board                           |
| CAA    | Clean Air Act   |
| DOT    | Department of Transportation                              |
| EPA    | Environmental Protection Agency                           |
| FHWA   | Federal Highway Administration                            |
| MPO    | Metropolitan Planning Organization                        |
| NAAQS  | National Ambient Air Quality Standards                    |
| NEPA   | National Environmental Policy Act                         |
| ODOT   | Ohio Department of Transportation                         |
| OKI    | Ohio, Kentucky and Indiana Regional Council of Government |
| PM     | Particulate Matter  |
| SIP    | State Air Quality Implementation Plan                     |
| TDF    | Travel Demand Forecasting                                 |
| TAEHIA | Traffic Air Environmental Health Impact Analysis          |
| TCM    | Transportation Control Measures                           |
| TRB    | Transportation Research Board                             |
| VMT    | Vehicle Miles Traveled                                    |

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## LIST OF ABBREVIATIONS

|            |                                  |
|------------|----------------------------------|
| ft         | Feet                             |
| g          | Gram                             |
| g/mile     | Grams Per Mile                   |
| g/s        | Grams Per second                 |
| g/veh/mile | Grams Per Vehicle Per Mile       |
| km         | Kilometer                        |
| ln         | Lane                             |
| m          | Meter                            |
| mph        | Miles Per Hour                   |
| pc/hr/ln   | Passenger Cars Per Hour Per Lane |
| s          | Second                           |
| km         | Kilometer                        |
| veh/h      | Vehicles Per Hour                |

| <b>SI* (MODERN METRIC) CONVERSION FACTORS</b>                      |                             |                             |                             |                     |
|--|-----------------------------|-----------------------------|-----------------------------|---------------------|
| <b>APPROXIMATE CONVERSIONS TO SI UNITS</b>                         |                             |                             |                             |                     |
| <b>Symbol</b>  | <b>When You Know</b>        | <b>Multiply By</b>          | <b>To Find</b>              | <b>Symbol</b>       |
| <b>LENGTH</b>  |                             |                             |                             |                     |
| in   | inches                      | 25.4                        | millimeters                 | mm                  |
| ft   | feet                        | 0.305                       | meters                      | m                   |
| yd   | yards                       | 0.914                       | meters                      | m                   |
| mi   | miles                       | 1.61                        | kilometers                  | km                  |
| <b>AREA</b>  |                             |                             |                             |                     |
| in <sup>2</sup>  | square inches               | 645.2                       | square millimeters          | mm <sup>2</sup>     |
| ft <sup>2</sup>  | square feet                 | 0.093                       | square meters               | m <sup>2</sup>      |
| yd <sup>2</sup>  | square yard                 | 0.836                       | square meters               | m <sup>2</sup>      |
| ac   | acres                       | 0.405                       | hectares                    | ha                  |
| mi <sup>2</sup>  | square miles                | 2.59                        | square kilometers           | km <sup>2</sup>     |
| <b>VOLUME</b>  |                             |                             |                             |                     |
| fl oz  | fluid ounces                | 29.57                       | milliliters                 | mL                  |
| gal  | gallons                     | 3.785                       | liters                      | L                   |
| ft <sup>3</sup>  | cubic feet                  | 0.028                       | cubic meters                | m <sup>3</sup>      |
| yd <sup>3</sup>  | cubic yards                 | 0.765                       | cubic meters                | m <sup>3</sup>      |
| NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup> |                             |                             |                             |                     |
| <b>MASS</b>  |                             |                             |                             |                     |
| oz   | ounces                      | 28.35                       | grams                       | g                   |
| lb   | pounds                      | 0.454                       | kilograms                   | kg                  |
| T  | short tons (2000 lb)        | 0.907                       | megagrams (or "metric ton") | Mg (or "t")         |
| <b>TEMPERATURE (exact degrees)</b>                                 |                             |                             |                             |                     |
| °F   | Fahrenheit                  | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius                     | °C                  |
| <b>ILLUMINATION</b>  |                             |                             |                             |                     |
| fc   | foot-candles                | 10.76                       | lux                         | lx                  |
| fl   | foot-Lamberts               | 3.426                       | candela/m <sup>2</sup>      | cd/m <sup>2</sup>   |
| <b>FORCE and PRESSURE or STRESS</b>                                |                             |                             |                             |                     |
| lbf  | poundforce                  | 4.45                        | newtons                     | N                   |
| lbf/in <sup>2</sup>  | poundforce per square inch  | 6.89                        | kilopascals                 | kPa                 |
| <b>APPROXIMATE CONVERSIONS TO SI UNITS</b>                         |                             |                             |                             |                     |
| <b>Symbol</b>  | <b>When You Know</b>        | <b>Multiply By</b>          | <b>To Find</b>              | <b>Symbol</b>       |
| <b>LENGTH</b>  |                             |                             |                             |                     |
| mm   | millimeters                 | 0.039                       | inches                      | in                  |
| m  | meters                      | 3.28                        | feet                        | ft                  |
| m  | meters                      | 1.09                        | yards                       | yd                  |
| km   | kilometers                  | 0.621                       | miles                       | mi                  |
| <b>AREA</b>  |                             |                             |                             |                     |
| mm <sup>2</sup>  | square millimeters          | 0.0016                      | square inches               | in <sup>2</sup>     |
| m <sup>2</sup>   | square meters               | 10.764                      | square feet                 | ft <sup>2</sup>     |
| m <sup>2</sup>   | square meters               | 1.195                       | square yard                 | yd <sup>2</sup>     |
| ha   | hectares                    | 2.47                        | acres                       | ac                  |
| km <sup>2</sup>  | square kilometers           | 0.386                       | square miles                | mi <sup>2</sup>     |
| <b>VOLUME</b>  |                             |                             |                             |                     |
| mL   | milliliters                 | 0.034                       | fluid ounces                | fl oz               |
| L  | liters                      | 0.264                       | gallons                     | gal                 |
| m <sup>3</sup>   | cubic meters                | 35.314                      | cubic feet                  | ft <sup>3</sup>     |
| m <sup>3</sup>   | cubic meters                | 1.307                       | cubic yards                 | yd <sup>3</sup>     |
| <b>MASS</b>  |                             |                             |                             |                     |
| g  | grams                       | 0.035                       | ounces                      | oz                  |
| kg   | kilograms                   | 2.202                       | pounds                      | lb                  |
| Mg (or "t")  | megagrams (or "metric ton") | 1.103                       | short tons (2000 lb)        | T                   |
| <b>TEMPERATURE (exact degrees)</b>                                 |                             |                             |                             |                     |
| °C   | Celsius                     | 1.8C+32                     | Fahrenheit                  | °F                  |
| <b>ILLUMINATION</b>  |                             |                             |                             |                     |
| lx   | lux                         | 0.0929                      | foot-candles                | fc                  |
| cd/m <sup>2</sup>  | candela/m <sup>2</sup>      | 0.2919                      | foot-Lamberts               | fl                  |
| <b>FORCE and PRESSURE or STRESS</b>                                |                             |                             |                             |                     |
| N  | newtons                     | 0.225                       | poundforce                  | lbf                 |
| kPa  | kilopascals                 | 0.145                       | poundforce per square inch  | lbf/in <sup>2</sup> |

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.  
(Revised March 2003)

## CHAPTER 1 : INTRODUCTION

### 1.1 Background and Research Motivation

All State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) have been required to use the MOVES2010 (Motor Vehicle Emission Simulator), an upgraded state-of-the-art model, for new regional emissions analyses for transportation conformity determinations outside of California that began after March 2, 2013 (U.S. EPA, 2012a; 2012b). In addition, the U.S. Environmental Protection Agency (EPA) regulates that this model also be required for new PM hot-spot analyses for project-level conformity determinations starting from December 20, 2012 (U.S. EPA, 2012b). Localized traffic data inputs to the model are crucial to maximizing its capability of accurately reflecting the emissions for criteria pollutants (i.e., ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead) and greenhouse gases (GHGs) associated with transportation programs and projects. They also greatly influences the assessment of emission reduction benefits associated with local-level or large-scale pricing-oriented transportation control measures (TCMs), which may improve travel times, alleviate congestion, and reduce stop-and-go traffic (U.S. EPA, 2010b & 2011). Therefore, it is a critical need to identify existing traffic data sources for generating traffic data sets that can reflect real-time vehicle operating characteristics, and develop a user-friendly tool to facilitate the adaptation of the those datasets into proper inputs for increasing the efficiency of MOVES2010 applications in practical projects and research activities.

Many previous studies suggested that use of reliable local on-road traffic data can significantly improve the accuracy of local scale air quality modeling assessments, when applying MOVES2010 for project-level conformity analysis (U.S. EPA 2010a; Oge, 2010; Nemapuri, 2010; Hatzopoulou et al., 2008). For a project-level conformity analysis, the MOVES2010 calculates emissions from each roadway link for a given time period (or run). Fractions of the link traffic volume and average speed are input by vehicle type, which is further defined as an emission source type in MOVES2010 (U.S. EPA, 2010a). Heavy truck traffic has been recognized as one of the major sources of Particulate Matter (PM) emission, and on-road traffic related emission varies with traffic operating conditions (e.g., speed, acceleration or deceleration) and fleet compositions or vehicle fraction (i.e., percentage of each vehicle type in the traffic stream) (U.S. EPA, 2011; Frey, 2006; Qu et al., 2008; Song, et al., 2007; Lin et al., 2011; Fulper et al., 2011; Chamberlin et al., 2011; Johansson et al., 2007). Operating mode distribution is one of the critical variables representing the attribute of a link traffic activity. The EPA recommends obtaining the data from either other locations with similar geometric and traffic characteristics, or outputs from micro-simulation models (U.S. EPA, 2010a). However, locally acquiring accurate fleet composition and relevant traffic operating data is always a challenge for real practical projects. Outcomes of running traffic simulation models are viewed as unreliable without passing their calibration and validation tests.

According to the new Federal Highway Administration (FHWA) and Ohio Department of Transportation (ODOT) guidance on project-level conformity and hot-spot analysis (ODOT, 2014; Ogulei et al., 2007), “a PM<sub>2.5</sub> Hotspot Analysis is required if a non-exempt project is located in a PM<sub>2.5</sub> nonattainment or maintenance area and the project's design year Average Daily Traffic (ADT) > 125,000 and the design year diesel truck volume > 10,000.” AADT is obviously an aggregated traffic feature without reflection of real-time operating situation, which may matter on some transportation projects. For instance, if temporal or permanent bottlenecks

on one or more links would occur due to a transportation project, traffic congestion is expected to greatly impact vehicle emissions. For the sake of this consideration, AADT and truck volume data alone might not be enough to assess the hot-spot requirement.

Many MPOs, such as OKI (Ohio, Kentucky and Indiana Regional Council of Government, Cincinnati, Ohio), have more experience with the regional level conformity analysis than the project level analysis. Traditional regional level analysis is conducted with the aid of a travel demand forecasting (TDF) model. Some validation studies suggested potential shortcomings in converting travel demand outputs into the emission model inputs in terms of underestimating the truck traffic volumes. These weaknesses can make the models less sensitive and inadaptable to scenario analysis (Nair et al., 2000; Kanaroglou et al., 2008). In order to connect regional level and project level results (Bachman et al., 2000) in a single platform, a GIS-based integrated approach or tool is expected to be helpful for investigating the impact of traffic operating situation on the existing criteria for the hot-spot requirement. Such a tool is also desired to be capable to assist investigating what and how ODOT's regional-level MOVES2010 inputs as well as how criteria could be considered as part of data for project-level analysis using MOVES2010.

Under the National Environmental Policy Act (NEPA), TDF models (regional- or macro-level models such as VISUM or CUBE) and microscopic simulation models (such as VISSIM) have been associated with mobile source emission and dispersion problems (e.g. by using CAL3QHCR and AERMOD). To facilitate the PM<sub>2.5</sub> project-level conformity analysis with the ODOT and EPA guidelines, an easy-to-use computer tool in the ArcGIS environment, termed as Traffic Air Environmental Health Impact Analysis (TAEHIA) supporting system, has been developed through the project. The TAEHIA is aimed to allow users to integrate the outcomes from micro- and macro traffic and emission models into the GIS environment for evaluating regional- and project-level input variables and outcomes in a single platform.

## 1.2 Significance of Research

The proposed research addresses the problems and challenges in identifying the traffic data needs and their applications in conducting the project-level PM<sub>2.5</sub> conformity analysis in an effective and efficient way, when MOVES2010 is used. The results are anticipated to provide a practical and convenient guidance with exemplary traffic datasets for MOVES2010 users in Ohio and other states. The guidance will also include the improved procedure for generating simulation-based inputs variables for MOVES2010 inputs variables that are difficult to obtain for a project, as well as data required for simulation model validation. The prototype of the developed TAEHIA is aimed to provide an effective tool for integrated transportation conformity analysis with capability to visualize and manipulate the results from both regional- and project-level analyses in a single platform. It will make it possible to quickly identify the emission variations as a result of interactive changes in input variables between regional and project or local level properties of the system (e.g., changes in land use and social economic data at macro level or traffic control and operation situation at micro level). With the use of the TAEHIA, it will become possible to identify the traffic operating factors and associated criteria for requiring the not-spot analysis. More importantly, the prototype of the TAEHIA provides a solid foundation for future possible expansion of the functionality to conduct "what if" environmental impact analysis of various scenario-based planning alternatives for sustainable community planning and/or associated improvement of traffic control measures. Finally, this study provides

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an opportunity to build up the interdisciplinary knowledge base of the PM<sub>2.5</sub> emission-related problems in an integrated manner.

### **1.3 Report Organization**

This report is organized into eight chapters. Chapter 1 reviews the background of this research and refreshes the purpose and significance of the study. Chapter 2 states the goal and objectives of the research and describes the framework of the methodology to be applied in this research. Chapter 3 reviews and summarizes previous studies based on an intensive literature review. Chapter 4 describes the available traffic data sources, the challenge of applying these sources into PM<sub>2.5</sub> conformity analysis and the methodology of addressing these challenges. Chapter 5 evaluates the applicability of the available traffic data sources. Chapter 6 covers the development of the TAEHIA tool. Chapter 7 presents the case studies performed by using the TAEHIA. Chapter 8 summarizes and concludes the research results and provides recommended an implementation plan for applying the available data sources with the aid of the TAEHIA system. Besides the project-level module, TAEHIA also offers a regional analysis module that can be used for regional PM<sub>2.5</sub> analysis. Details of the TAEHIA regional module is provide in the appendix.

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## CHAPTER 2 : RESEACH GOAL AND OBJECTIVES

### 2.1 Goal

The goal of this project is to provide an integrated approach and supportive GIS-based tool to formulate and facilitate the application of Ohio traffic data sources into project-level PM<sub>2.5</sub> conformity analysis.

### 2.2 Objective

To achieve the goal, the proposed research project is designed to fulfill the following objectives:

- To identify traffic data needs for PM<sub>2.5</sub> conformity analysis using MOVES2010 and availability of Ohio data sources for the analysis.
- To analyze the applicability of the available traffic data sources and evaluate the impact of applying different data sources for the PM<sub>2.5</sub> analysis.
- To develop a GIS-based integrated PM<sub>2.5</sub> conformity analysis tool, i.e., TAEHIA and TAEHIA guidance with demonstrated case studies. In addition to demonstrating the TAEHIA's functions for the PM<sub>2.5</sub> conformity analysis, the case studies are also aimed to:
  - Identify traffic operating related criteria to be needed for requiring PM<sub>2.5</sub> hot-spot analysis;
  - Identify the impact of traffic control measures on project-level emission assessments.



## CHAPTER 3 : LITERATURE REVIEW

### 3.1 PM<sub>2.5</sub> Conformity Analysis

Transportation conformity is a Clean Air Act (CAA) requirement to ensure that federally supported highway and transit activities are consistent with (“conform to”) the State air quality Implementation Plan (SIP) (Oge, 2010). Conformity to a SIP means that a transportation activity will not cause or contribute to new air quality violations, worsen existing violations, or delay timely attainment of the National Ambient Air Quality Standards (NAAQS) or any interim milestone.

In 1997, U.S. EPA issued the PM<sub>2.5</sub> fine particulate NAAQS in order to protect public health. The annual standard is set at 15 micrograms per cubic meter and is based on a 3-year average of annual mean PM<sub>2.5</sub> concentrations. The 24-hour standard is currently set at a level of 65 micrograms per cubic meter, and is determined by the 3-year average of annual 98th percentile concentrations (U.S. EPA 2006). Areas that have failed to meet the standards outlined above have been designated as nonattainment areas. Transportation conformity requires nonattainment areas to demonstrate that all future transportation projects will not hinder the area from reaching its attainment goals.

According to the U.S. EPA’s hot-spot PM<sub>2.5</sub> analysis guideline (U.S. EPA, 2010b), data needed for the project-level PM<sub>2.5</sub> conformity analysis is shown in Table 3-1. This project is focused on estimating emission factor based on the available traffic data sources. The PM<sub>2.5</sub> precursors, road dust and construction related fugitive dust are required to be considered in the regional PM<sub>2.5</sub> conformity analysis. Since they are out of the scope of this project, they are only briefly introduced in Sections 3.1.1 and 3.1.2.

**Table 3-1 Data needs for PM<sub>2.5</sub> conformity analysis**

| <b>Data Category</b> | <b>Description</b>  |
|----------------------|---|
| Emission factor      | Hourly emission factor of each emission source. The emission factor should cover a typical day of a season and four seasons of a year.  |
| Build environment    | Features of project area, including geometry of study road segment, alignment of receptors, terrain of the project area, if the project site is located in an urban or rural area and population if the project area is located in an urban area. |
| Meteorology          | One-year meteorology data, including surface and upper air profile, if measured on site Five-year meteorology data (if obtained from nearby airport).   |

#### 3.1.1 PM<sub>2.5</sub> Precursors

For transportation conformity, four PM<sub>2.5</sub> precursors: NO<sub>x</sub>, VOCs, SO<sub>x</sub>, and NH<sub>3</sub> must be considered in the conformity process in PM<sub>2.5</sub> nonattainment areas (Esworthy, 2012). The U.S. EPA requirements for the consideration of PM<sub>2.5</sub> precursors are:

- Regional emissions analysis must include NO<sub>x</sub> as a PM<sub>2.5</sub> precursor in all PM<sub>2.5</sub> nonattainment areas, unless the head of the state air agency and the U.S. EPA Regional

Administrator make a finding that  $\text{NO}_x$  is not a significant contributor to the  $\text{PM}_{2.5}$  air quality problem in a given area.

- Regional emissions analyses are not required for VOC,  $\text{SO}_x$  or  $\text{NH}_3$  before an approved SIP budget for such precursors is established, unless the head of the state air agency or the U.S. EPA Regional Administrator makes a finding that on-road emissions of any of these precursors is a significant contributor.
- The following criteria are considered in making significance or insignificance findings for  $\text{PM}_{2.5}$  precursors:
  - The contribution of on-road emissions of the precursor to the total 2002 baseline SIP inventory ;
  - The current state of air quality for the area;
  - The results of speciation monitoring for the area;
  - The likelihood that future motor vehicle control measures will be implemented for a given precursor; and,
  - Projections of future on-road emissions of the precursor.

The transportation conformity budgets for  $\text{PM}_{2.5}$  precursors will only include the establishment of an annual  $\text{NO}_x$  budget for the  $\text{PM}_{2.5}$  nonattainment area addressed by this attainment demonstration SIP revision.

### *3.1.2 Road Dust and Construction Related Fugitive Dust*

The Federal Transportation Conformity Rule specifies that re-entrained road dust is to be included as a component of direct  $\text{PM}_{2.5}$  for transportation conformity regional emissions analysis only if the U.S. EPA Regional Administrator or the director of the State air agency has made a finding that emissions from re-entrained road dust within the area are a significant contributor to the  $\text{PM}_{2.5}$  nonattainment problem and has so notified the MPO and the Department (U.S. EPA, 2006). Also, for  $\text{PM}_{2.5}$  areas in which the implementation plan does not identify construction-related fugitive  $\text{PM}_{2.5}$  as a significant contributor to the nonattainment problem, the fugitive  $\text{PM}_{2.5}$  emissions associated with highway and transit project construction are not required to be considered in the regional emissions analysis.

The U.S. EPA has indicated that a finding of significance for re-entrained road dust should be based on a case-by-case review of the following factors: the contribution of road dust to current and future  $\text{PM}_{2.5}$  nonattainment; an area's current design value for the  $\text{PM}_{2.5}$  standard; whether control of road dust appears necessary to reach attainment; and whether increases in re-entrained dust emissions may interfere with attainment. Such a review should include consideration of local air quality data and/or air quality or emissions modeling results.

## **3.2 Traffic Data Needs for $\text{PM}_{2.5}$ Conformity Analysis**

### *3.2.1 Emission models*

Traffic data are used to estimate the emission factors using the emission models. The MOVES model is the U.S. EPA required model for estimating transportation emissions. Thus, it is adapted in the project as the emission analysis tool. In 2010, the MOVES model was released by the U.S. EPA to replace MOBILE6.2 model (U.S. EPA, 2010a). The purpose of the tool is to provide an accurate estimate of emissions from mobile sources under a wide range of user-defined conditions. The MOVES model is different from previous U.S. EPA mobile source emissions models in that it was deliberately designed to work with databases. Therefore, new

emissions test data that may become available later on can be easily incorporated into the model. In addition, both regional level and project level emission analysis can be performed with MOVES (U.S. EPA, 2010a). The MOVES model provides choices of operating modes to evaluate project-level emissions by simulating varying vehicle operating modes. In addition to the MOVES model, other emission models are available. These models are briefly reviewed as follows.

#### MOBLIE model

MOBILE6 was designed by the U.S. EPA to address a wide variety of air pollution modeling needs. MOBILE6 is a computer program that estimates HC, CO, NO<sub>x</sub>, PM, SO<sub>2</sub>, NH<sub>3</sub>, HAP, and CO<sub>2</sub> emission factors for gasoline-fueled and diesel highway motor vehicles, and for certain special vehicles such as natural-gas-fueled or electric vehicles for calendar years between 1952 and 2050. MOBILE6 calculates average in-use fleet emission factors for 28 individual vehicle types in low- and high-altitude regions of the United States (U.S. EPA, 2001). MOBILE6 emission factor estimates depend on various conditions, such as ambient temperatures, travel speeds, operating modes, fuel volatility, and mileage accrual rates. MOBILE6.2 is the latest in a series of MOBILE models dating back to 1978. MOBILE6.2 incorporates updated information on basic emission rates, more realistic driving patterns, and separation of start and running emissions, improved correction factors, and changing fleet composition (U.S. EPA, 2003).

#### EMFAC model

The California's Air Resource Board (ARB) developed an EMission FACTors (EMFAC) model to calculate emission rates from all motor vehicles. In 2011, California ARB released an updated version of the EMFAC model-EMFAC2011. In the EMFAC2011, the emission rates are multiplied with vehicle activity data provided by the regional transportation agencies to calculate the statewide or regional emission inventories (California EPA, 2011). The EMFAC2011 model is a computer model that can estimate emission rates for on-road mobile sources for calendar years from 1970 to 2040 operating in California. Pollutant emissions for HC, CO, NO<sub>x</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, lead, and sulfur oxides are output from the model. Emissions are calculated for thirteen different vehicles classes comprised of passenger cars, various types of trucks and buses, motorcycles, and motor homes. EMFAC is used to calculate current and future inventories of motor vehicle emissions at the state, air district, air basin, or county level. EMFAC2011 models on-road mobile source emissions under multiple temporal and spatial scales. It produces composite emission factors for an average day of a month (from January to December), a season (summer and winter), or an annual average, for specific California geographic areas by air basin, district, and county as well as statewide level. EMFAC can produce PM<sub>2.5</sub> and PM<sub>10</sub> emission rates for three exhaust emission processes (running, starting, and idle), tire wear, and brake wear.

#### CMEM model

Comprehensive Modal Emissions Model, or CMEM, was initially developed in the late 1990's with sponsorship from the National Cooperative Highway Research Program (NCHRP) and the U.S. EPA to fulfill the need for microscopic emissions modeling. The model was developed at the University of California, Riverside as a fine-scale emissions predictions model that was specifically designed to improve the prediction of the variation of the vehicle's operating conditions. CMEM was developed to meet the need for an emissions modeling system in response to traffic operational changes (i.e. the various driving 'modes', such as idle, steady-state cruise, various levels of acceleration/deceleration). CMEM integrates with existing micro-

simulation software packages that generate second-by-second speed/acceleration vehicle profiles (or trajectories). CMEM is microscopic because it predicts second-by-second tailpipe emissions and fuel consumption based on different modal operations from in-use vehicle fleet (Scora and Barth, 2006.). One of the most important features of CMEM is that it uses a physical, power-demand approach based on a parameterized analytical representation of fuel consumption and emissions production. In this type of model, the entire fuel consumption and emissions process is broken down into components that correspond to physical phenomena associated with vehicle operation and emissions production. Each component is modeled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary according to the vehicle type, engine, emission technology, and level of deterioration. One distinct advantage of this physical approach is that it is possible to adjust many of these physical parameters to predict energy consumption and emissions of future vehicle models.

### Comparison of models

In above emission models, the MOVES model is more capable than the MOBILE emission models in estimating the impacts of traffic operational changes, and has replaced the MOBLIE model. Although EMFAC aggregates regional and national analyses of emissions and air quality, it could not be used for assessment of mobile source emissions at temporal and spatial scales relevant to specific transportation projects and control measures. Estimating exhaust emission factors using the EMFAC model are based upon cycle-average emissions with average speed. The MOVES model provides greater flexibility to evaluate project-level emissions by allowing the user to input any vehicle operation cycle and estimate running exhaust emissions as a function of vehicle-specific power, the instantaneous power demand of the vehicle divided by its mass. As a micro-simulation emission model, a drawback of the CMEM model for macroscopic applications or areas is the extensive amount of input data required.

#### *3.2.2 Traffic Data Needs for MOVES Analysis*

The data needs for estimating project-level emission factor by using the MOVES model are summarized in Table 3-2 (U.S. EPA, 2012a). In this project, the methodology for extracting the traffic data from available data sources is developed.

**Table 3-2 Data needs for MOVES project-level analysis**

|                  | <b>Data Category</b>  | <b>Data Items</b>           |
|------------------|-----------------------|-----------------------------|
| Traffic Data     | Traffic activity data | Average speed               |
|                  |                       | Link drive schedule         |
|                  |                       | Operating mode distribution |
|                  | Link traffic          | Link volume                 |
|                  | Fleet Composition     | Link source types           |
| Non-traffic Data | Meteorology           | Temperature                 |
|                  |                       | Relative humidity           |
|                  | Fuel information      | Fuel supply                 |
|                  |                       | Fuel formulation            |
| Vehicle age      | Age distribution      |                             |

### 3.3 Dispersion models

Dispersion modeling is a mathematical simulation of emissions as they are transported throughout the atmosphere which uses mathematical equations describing the atmosphere, dispersion and chemical and physical processes within the plume to calculate concentrations at various locations. In this project, the dispersion model is used to estimate the roadside PM<sub>2.5</sub> concentration based on the available data sources. The modeled concentrations are compared to the observed data for the purpose of evaluating the applicability of the available data sources. Numerous studies in the past have covered dispersion models that address wind flow and pollutant dispersions at vehicle wake, roadside locations, intersections, street canyons, neighborhood and city scales. The line source dispersion models that have been developed to simulate dispersion from roadways are introduced in this section.

#### AERMOD model

AERMOD (U.S. EPA) is a near field steady state Gaussian plume model based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources over both simple and complex terrain. It is able to model multiple sources of different types including point, area and volume. In the stable boundary layer, the distribution is assumed to be Gaussian in both the horizontal and vertical directions. However, in the convective boundary layer, the vertical distribution is described using a bi-Gaussian probability density function, developed by Wills and Deardorff (1981), whilst the horizontal distribution is considered to be Gaussian. AERMOD is capable to model buoyant plumes and incorporates a treatment of lofting, whereby the plume remains near the top of the boundary layer before mixing with the CBL. In general, Gaussian models are limited to treatments of flows over a simple terrain; however, AERMOD incorporates a simple method to approximate flows over complex terrain (Snyder et al., 1985). There are two input data processors that are regulatory components of the AERMOD modeling system: AERMET, a meteorological data preprocessor that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, and AERMAP, a terrain data preprocessor that incorporates complex terrain using USGS Digital Elevation Data. Other non-regulatory components of the system include: AERSCREEN, a screening version of AERMOD; AERSURFACE, a surface characteristics preprocessor, and BPIPPRIME, a multi-building dimensions program incorporating the GEP technical procedures for PRIME applications. (U.S. EPA, 2004b).

#### CALINE model

Beaton et al. (1972) published the first version of the California Line (CALINE) Source Dispersion Model. It consisted of a series of tables and monographs that enabled the user to predict CO concentrations near roadways based on estimated meteorology and traffic. The transport and dispersion element of the model was a modified form of the Gaussian point source plume dispersion model. Ward et al. (1975) updated the original model with CALINE2. The model was able to compute concentrations for depressed sections and for winds parallel to the roadway (Benson, 1992.). However, subsequent studies indicated that CALINE2 seriously overestimated concentrations of stable, parallel wind conditions. CALINE3 (Benson, 1979) and its variants CAL3QHC and CAL3QHCR are series of the CALINE models. Those models have been recognized as appropriate for regulatory uses in roadway applications for CO and PM estimations. CALINE4 is the updated version of CALINE series (Benson, 1984). The primary differences in the model formulations of CALINE3 and CALINE4 are related to the lateral

dispersion curves and the introduction of vehicle-induced turbulence in CALINE4. CALINE4 is based on a Gaussian plume model and suffer the limitations of urban modeling over short distances and within complex environments. Additionally, this is not recommended in low wind speeds (Holmes and Morawska, 2006).

#### RLINE model

Research LINE source dispersion model (RLINE), a steady-state, line-source dispersion model, is designed to primarily simulate chemically inert pollutants with an emphasis on near surface releases and near source dispersion. It is based on Romberg numerical integration of the contributions of point sources along a line (road segment). This approach allows the incorporation of the governing process without introducing errors associated with approximating the underlying model framework. The meteorology that drives RLINE is from the surface file output from AERMOD's met processor, AERMET (Cimorelli et al., 2005). The concentration from a finite line source in RLINE is found by approximating the line as a series of point sources. Each point source is simulated using a Gaussian plume formulation. However, RLINE has a limit for the effective wind speed user in the dispersion calculations that is a function of the lateral turbulence (Michelle et al., 2013). RLINE model is not appropriate for regulatory applications because it has not undergone the extensive testing and comprehensive evaluation for such regulatory use (Snyder and Heist, 2013).

#### HIWAY model

HIWAY model was developed by U.S. EPA to estimate pollutant concentrations due to vehicles. In this model each lane of traffic modeled as if it were a straight continuous, finite line source with uniform rate. Air pollution concentrations downwind from a line source are found by a numerical integration along the line source of a simple Gaussian point-source plume (Petersen, 1980.). HIWAY2 is similar to the line-source equations in the workbook of Atmospheric Dispersion Estimates (Turner, 1970) but can also consider finite line source at an angle to the wind. Different from CALINE4, vertical dispersion parameters considered in HIWAY2 only take the effects of vehicles, whilst CALINE4 considers both thermal and mechanical turbulence.

#### CAR-FMI model

CAR-FMI (Contaminants in the Air from a Road-Finish Meteorological Institute) model is a Gaussian Plume model based on the equations of Luhar and Patil (1989). It was designed to calculate the hourly concentrations of CO, NO, NO<sub>2</sub>, NO<sub>x</sub>, and PM<sub>2.5</sub> from vehicles. Atmospheric stability is defined using Boundary layer scaling. CAR-FMI is limited to low wind conditions. The horizontal and vertical dispersion parameters included turbulence terms from ambient wind speed, exhaust velocities and vehicles. CAR-FMI contains treatment of dry deposition for three particle size groups. Another limitation of this model is that it is not able to predict the meandering wind flow under low wind speed (Oetl et al., 2001).

#### ADMS model

ADMS (Atmospheric Dispersion Modeling System) model is a general purpose dispersion model capable of modeling point, line, area and volume source types in a variety of atmospheric conditions (McHugh et al., 1997). It uses Monin-Obukhov similarity to define the structure of the boundary layer and computes steady state Gaussian solutions (non-Gaussian in the vertical for convective conditions as with AERMOD) to describe the diffusion of pollutants. For line sources such as roadways, ADMS decomposes the source 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. To improve computational speed, portions of the line that are sufficiently far laterally from the receptor are ignored. An integrated input module processes meteorological data to produce parameters required to run the model (Heist et al., 2013). ADMS-Roads model, the version of ADMS designed for simulating traffic sources, includes algorithms that account for traffic-produced turbulence, and the presence of roadside noise barriers, and has an integrated street canyon model (Cambridge Environmental Research Consultants, 2011).

The basic parameters of these dispersion models are listed in Table 3-3.

**Table 3-3 Basic parameters for dispersion models**

| MODELS                   | AERMOD                            | CALINE 4   | HIWAY2  | CAR-FMI   | RLINE                        | ADMS   |
|--------------------------|-----------------------------------|--|---|---|------------------------------|--|
| Model type               | Bi Gaussian;<br>Gaussian<br>Plume | Gaussian<br>Plume  | Gaussian<br>Plume   | Gaussian<br>Plume   | Gaussian<br>Plume            | Gaussian Plume   |
| Scale                    | Local,<br>regional                | Local  | local   | Local   | Local                        | Local, regional  |
| Grid size                | <50Km                             | 100-500m   | 10-100m but<br>up to 10km<br>depending on<br>scaling factor       | Up to 10km  | <50Km                        | 3000 grid size<br>up to 500km                                  |
| Resolution               | No limits                         | 1m   | 1m  | Adjustable  | No limits                    | No limits  |
| Source types             | Point, line,<br>area, volume      | Line   | local   | Line  | Point, line,<br>area, volume | Point, line, area  |
| Output<br>frequency      | 1h,24h, 1yr                       | 1h, 8h, worst<br>case  | 1h  | 1h,8h,24h,1yr   | 1h,24h, 1yr                  | 10 mins to 1yr   |
| Atmospheric<br>stability | Boundary<br>layer scaling         | Pasquil  | Pasquil   | Boundary<br>layer scaling   | Boundary<br>layer scaling    | Boundary layer<br>scaling                                      |
| Turbulence               | Turbulence of<br>ambient air      | Vehicle<br>induced<br>turbulence;<br>Turbulence<br>of ambient<br>air | Vehicle<br>induced<br>turbulence;<br>Turbulence of<br>ambient air | Vehicle<br>induced<br>turbulence;<br>Turbulence of<br>ambient air | Turbulence of<br>ambient air | Vehicle induced<br>turbulence;<br>Turbulence of<br>ambient air |

## CHAPTER 4 : METHODOLOGY

### 4.1 Identification of Traffic Data Sources Available in Ohio

The traffic data sources available in Ohio have been identified through investigating the Ohio Department of Transportation (ODOT) website and consulting with ODOT technical liaisons. It is found that the traffic data in Ohio are mainly obtained from the automatic traffic recorders and short-term traffic data collection campaigns. In addition, traffic data at locations where no monitoring station is deployed may be projected through travel demand forecasting (TDF) analysis and/or microscopic simulation analysis. Accordingly, traffic data sources provided by these data collection methods are summarized in Table 4-1.

**Table 4-1 Summary of traffic data sources available in Ohio**

| Data Source                   | Traffic Data  | Collection Methods  | Comments   |
|-------------------------------|---|---|--|
| <b>ATR</b>                    | Traffic flow rate and fleet composition in 15-minute or 1-hour interval | Automatic traffic recorders; Short-term traffic data collection campaigns; TDF analysis | ATR data are mainly collected by automatic traffic recorders. ATR source is readily available at ODOT website.   |
| <b>PVR</b>                    | Individual vehicle timestamp, speed and class                           | Automatic traffic recorders; Short-term traffic data collection campaigns               | PVR (Per Vehicle Record) data source is not routinely archived due to its large data size. A request must be sent to ODOT so that they will save PVR data for the requested time period. |
| <b>Microscopic Simulation</b> | Individual vehicle class, speed and acceleration profiles               | Microscopic simulation analysis   | Great effort is needed to build up the simulation network, calibrate and validate the simulation model.  |

The ATR data source is mainly collected by using automatic traffic recorders. In addition, raw data obtained from the short-term traffic data collection campaigns and TDF analysis are usually compiled with the same format as the ATR data. And those datasets are also categorized as is the ATR data. The PVR data source contains the raw data collected by automatic traffic recorders or short-term traffic data collection campaigns. The micro-simulation data source stores outputs of microscopic simulation analysis. The micro-simulation and PVR data sources provide data on individual vehicles and the ATR data source provides aggregated traffic parameters calculated based on individual vehicle records. Sample data tables of the three traffic data sources are shown in Table 4-2 through Table 4-4.

**Table 4-2 Sample ATR data**

| Hour           | Vehicle Class |        |        |     |       |       |       | Total  |
|----------------|---------------|--------|--------|-----|-------|-------|-------|--------|
|                | 1             | 2      | 3      | ... | 13    | 14    | 15    |        |
| 0              | 3             | 1,257  | 170    | ... | 0     | 0     | 0     | 1,463  |
| 1              | 2             | 715    | 69     | ... | 1     | 0     | 0     | 814    |
| 2              | 1             | 504    | 60     | ... | 0     | 0     | 0     | 610    |
| ...            | ...           | ...    | ...    | ... | ...   | ...   | ...   | ...    |
| 22             | 1             | 1,522  | 190    | ... | 0     | 0     | 0     | 1,767  |
| 23             | 2             | 959    | 111    | ... | 0     | 0     | 0     | 1,126  |
| Total          | 97            | 55,211 | 7,172  | ... | 6     | 0     | 0     | 64,008 |
| Distribution % | 0.15%         | 86.26% | 11.20% | ... | 0.01% | 0.00% | 0.00% |        |



**Table 4-3 Sample PVR data**

| Vehicle ID | Lane ID | Timestamp | Speed (mph) | # of Axles | Space between Axles |       |       |       |
|------------|---------|-----------|-------------|------------|---------------------|-------|-------|-------|
| 1          | 1       | 0:00:27   | 66          | 2          | 8.7'                |       |       |       |
| 2          | 5       | 0:00:28   | 68          | 2          | 8.3'                |       |       |       |
| 3          | 2       | 0:00:29   | 67          | 2          | 9.1'                |       |       |       |
| 4          | 6       | 0:00:30   | 66          | 5          | 12.8'               | 20.4' | 9.3'  | 21.4' |
| 5          | 5       | 0:00:33   | 62          | 5          | 17.7'               | 4.3'  | 28.6' | 4.1'  |
| 6          | 6       | 0:00:38   | 65          | 5          | 15.3'               | 4.2'  | 33.0' | 4.0'  |

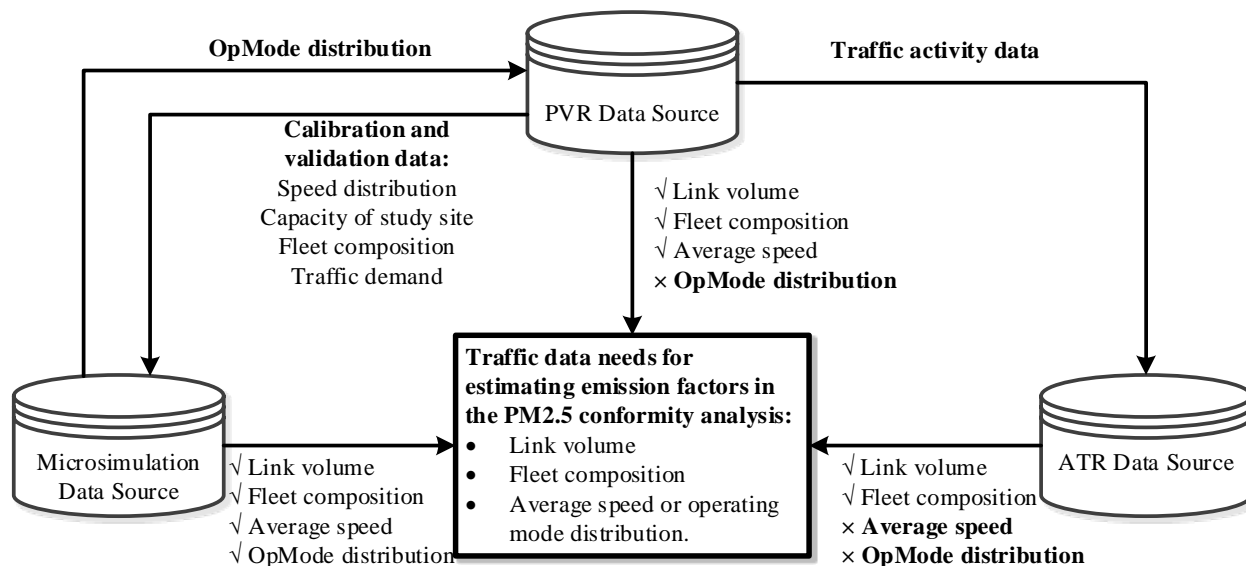
**Table 4-4 Sample micro-simulation data**

| Link ID | Time <sup>a</sup> | # of Cars | Car Speed <sup>b</sup> | Car Acceleration <sup>c</sup> | # of Trucks | Truck Speed | Truck Acceleration |
|---------|-------------------|-----------|------------------------|-------------------------------|-------------|-------------|--------------------|
| 2       | 1                 | 1         | 29.3                   | -0.21                         | 0           | 0           | 0                  |
| 3       | 2                 | 1         | 31.0                   | -0.18                         | 0           | 0           | 0                  |
| 1       | 3                 | 0         | 0                      | 0                             | 1           | 24.6        | -0.18              |
| 2       | 4                 | 1         | 27.1                   | 0.24                          | 0           | 0           | 0                  |

Note: <sup>a</sup> simulation time in seconds; <sup>b</sup> speed in m/s; <sup>c</sup> acceleration in m/s<sup>2</sup>.

## 4.2 Challenges to Applying Available Traffic Data Sources into PM<sub>2.5</sub> Conformity Analysis

In the PM<sub>2.5</sub> conformity analysis, traffic data are used to estimate the emission factors of the concerned road links. There are three major challenges for applying the available traffic data sources for estimating the emission factors. As shown in Figure 4-1, these challenges are identified in the process of mapping the available data sources onto the data needs as required by the PM<sub>2.5</sub> conformity analysis for estimating emission factors. First, lack of traffic activity information in the ATR data source makes it incapable of providing enough basic data to prepare traffic activity inputs (i.e., average speed, link drive schedule or operating mode distribution) for the MOVES model. The challenge with the PVR data source is the lack of vehicle acceleration information. Thus, it cannot be used to prepare the operating mode distribution, which is the preferred traffic activity input for the MOVES model. Finally, real-world traffic data are required to calibrate and validate the simulation model. Sections 4.3 through 4.5 of this chapter contain methods to address the above problems involved in estimating emission factors with the use of the three identified traffic data sources.



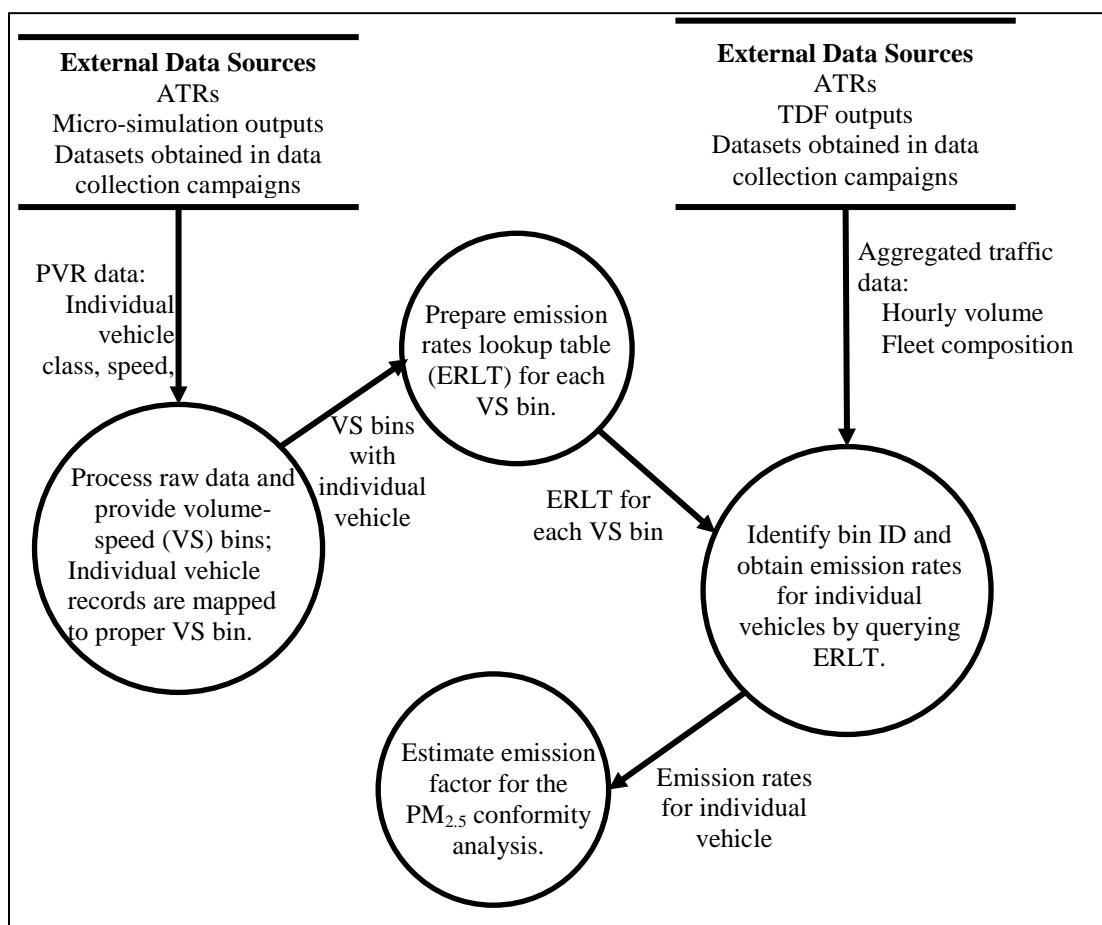
**Figure 4-1 Mapping traffic data needs for PM<sub>2.5</sub> conformity analysis and data sources available in Ohio**

### 4.3 Estimation of Emission Factor based on ATR Data Source

The ATR data source provides traffic flow rate and fleet composition in 15-minute and 1-hour intervals. Since average speed, link drive schedule, or operating mode distribution cannot be derived from the ATR data source, the traffic activity parameters as required by the MOVES model cannot be gained directly from the data source. In other words, the ATR cannot be directly used to generate the inputs required by the MOVES model to estimate emission factors. In order to address this problem, a methodology for estimating emission factors based on the ATR data source is developed in this section.

The methodological flowchart for estimating emission factors based on the ATR data is illustrated by Figure 4-2. As shown in Figure 4-2, the traffic volume from the ATR data source is used as the criterion to identify the traffic flow status or condition. Emission factors of individual vehicles recorded in the ATR data are then estimated based on the identified traffic flow status. In this procedure, a PVR dataset must be first collected at the sample site to provide detailed traffic data that contain individual vehicles' timestamp, speed and class that cannot be obtained from the ATR data source. The PVR dataset is then used to develop volume-speed (VS) bins, which are utilized to characterize traffic flow status. It is assumed that the emission rates of vehicles are very similar if they fall into the same VS bin and very different with different bins. Based on the assumption, an emission rates lookup table is developed to store the average car and truck emission rates for each VS bin. To this end, individual vehicle records in the PVR dataset are mapped to each VS bin, and the average emission rate of vehicles in a bin is then estimated by using the MOVES model. To apply the emission rates lookup table for the ATR data, the VS bin ID is identified in advance based on the traffic volume provided by the ATR data. The emission rates of individual vehicles in the ATR dataset can be identified through querying the emission rate lookup table by bin ID. Once the emission rates of individual vehicles are determined, the hourly emission factor can be calculated accordingly. The hourly emission

factor is one of variables that are used in the PM<sub>2.5</sub> conformity analysis. Details of the major components of the presented methodology are described in the following subsections of Section 4.3.



**Figure 4-2 Framework of estimating emission factor based on ATR data**

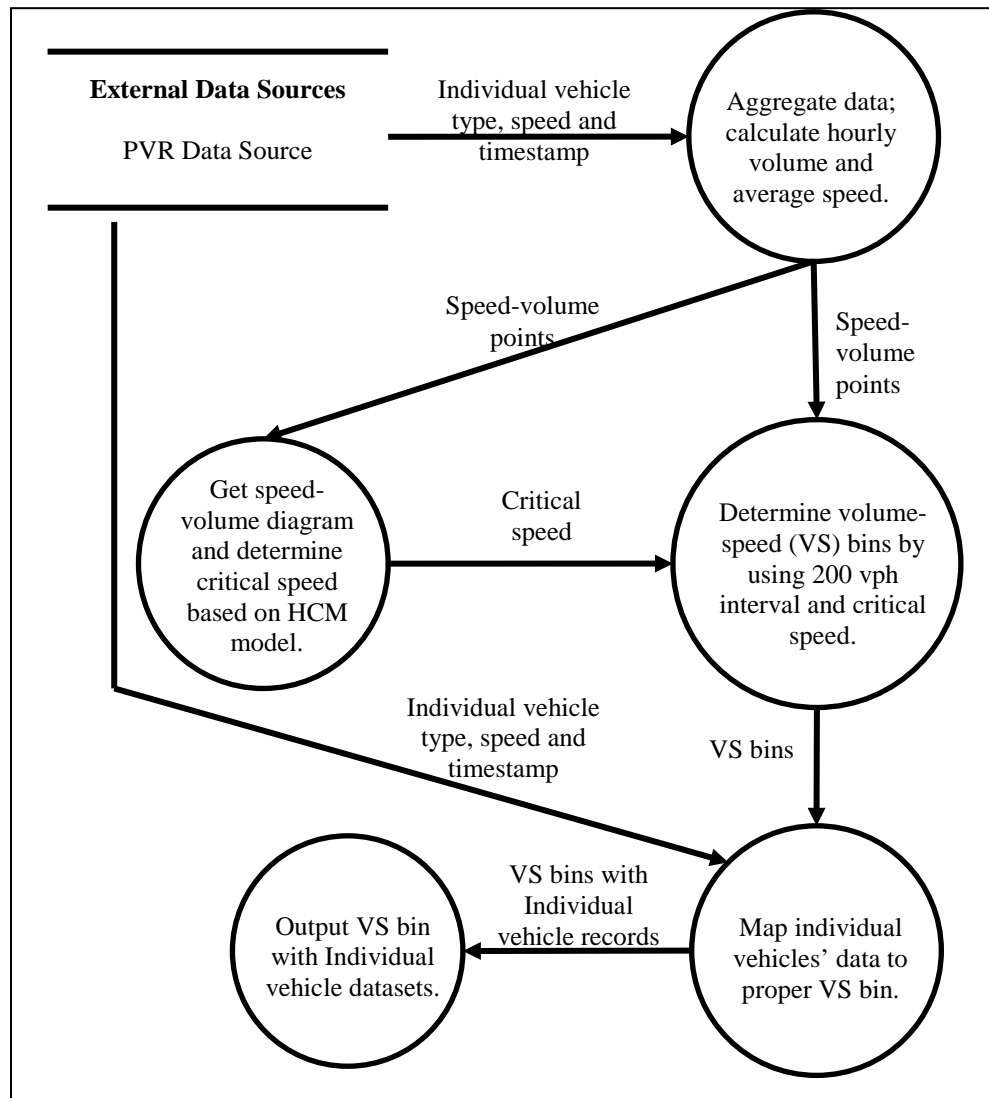
#### 4.3.1 Obtaining Traffic Activity Data from PVR Data Source

The PVR data source is used to provide traffic activity data as a supplementary dataset for the application of the ATR data. The PVR data are applied for this purpose since the PVR data and ATR data are collected through same traffic monitoring devices. Therefore, at sites where the ATR data are available, the PVR data can also be obtained. In order to get the PVR data, a request should be sent to the agency that operates the traffic monitoring devices (e.g., ODOT in this project). The agency will save the PVR data for the requested time period.

As required by the PM<sub>2.5</sub> conformity analysis guideline (U.S. EPA, 2010b), the emission factor should be estimated based on traffic activities observed in typical days. It is therefore recommended that the PVR data observed in weekdays are used to provide the traffic activity data. Specifically, the PVR data that are observed for at least five days (Monday through Friday) should be used to ensure enough collected vehicle samples to represent traffic patterns of weekdays.

### 4.3.2 Development of Volume-Speed Bins

The development of VS bins based on the PVR data is described in this section. The data flows for developing VS bins by are displayed by Figure 4-3.



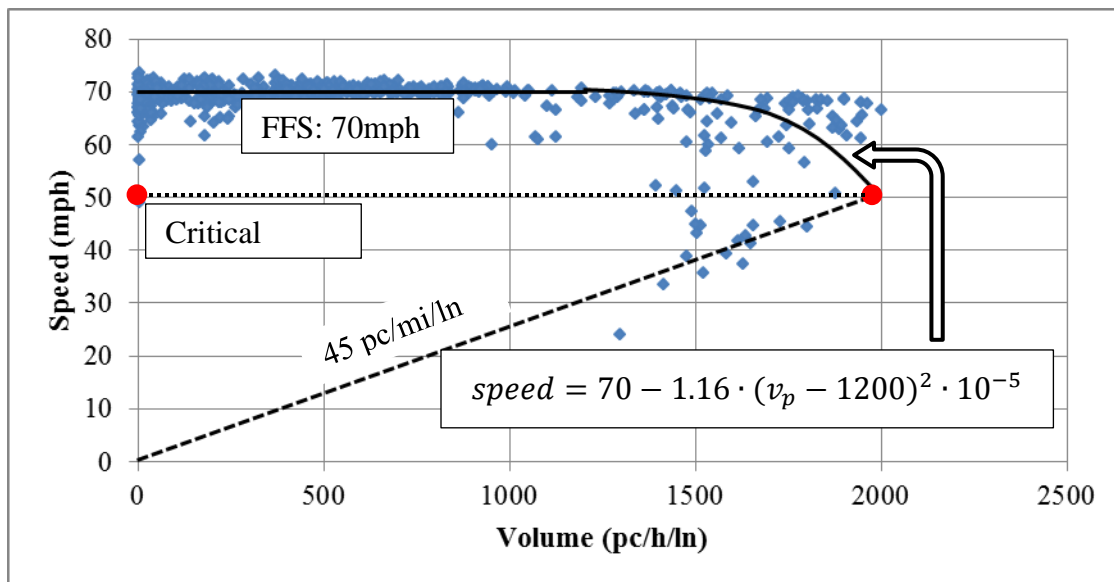
**Figure 4-3 Data flows of preparing volume-speed bins**

As shown by Figure 4-3, individual vehicles' records from the PVR dataset are used to prepare the speed-flow dataset in the first step. A sample point in the speed-flow dataset contains the hourly volume and the concurrent average speed which are calculated based on the individual vehicle records. The speed-flow datasets are used to construct the speed-flow diagram. The speed-flow diagram is then used to obtain the critical speed that distinguishes the free flow and congested flow status. According to the speed-flow model suggested in the Highway Capacity Manual (TRB, 2010), the critical speed is the intersection of the modeled speed-flow curve and a straight line representing the boundary density between Level of Service (LOS) E and F. In the

speed-flow diagram, the straight line starts from the origin with a slope of 45 cars/mile/lane. The estimation of the critical speed is demonstrated in Figure 4-4.

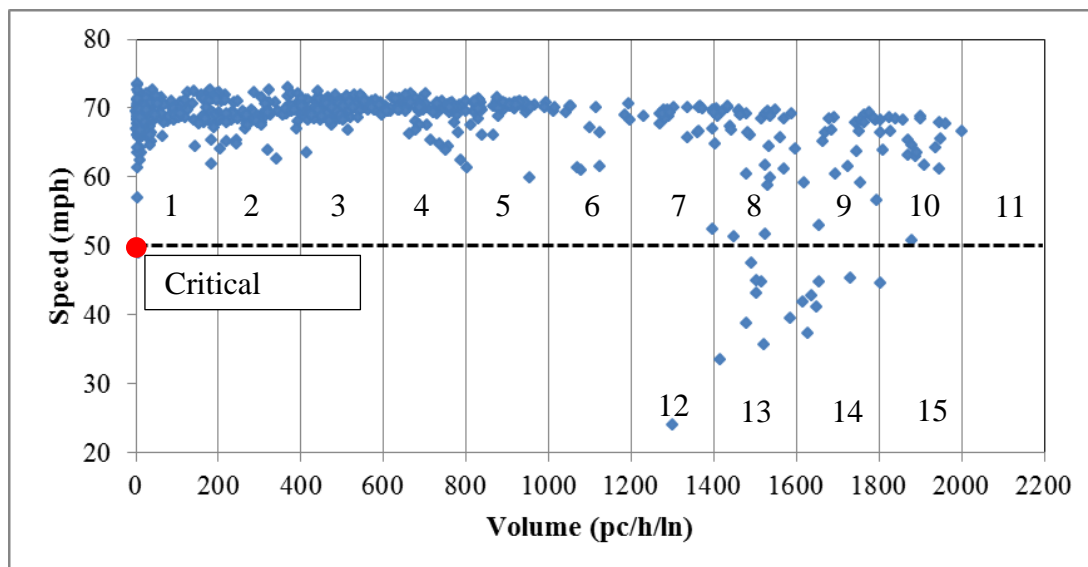
With the critical speed and the speed-volume points, the VS bins can be established. In the speed-flow dataset, all data points are first classified according to the traffic volume with 200 vehicles per hour increment. The critical speed is used to further divide the data points. For instance if the average speed of a speed-volume point is larger than the critical speed, it indicates that the point belongs to the free flow traffic status. After applying the volume interval and the critical speed, all points in the speed-volume dataset are assigned to certain VS bins. As shown by Figure 4-5, the VS bin IDs are identified for all the volume-speed points. In case there are no data points observed in a bin, the bin is skipped.

Lastly, the individual vehicles' records stored in the PVR dataset are mapped to proper VS bins. A vehicle record is linked to a speed-volume point if the vehicle was observed in the interval which the speed-volume point covers. Since each speed-volume point is linked to a VS bin, the individual vehicle records linked to the speed-volume point are also mapped to the same VS bin. The VS bins with individual vehicle record datasets are used to establish emission rates lookup table and relevant details will be presented in the next section.



Note: FFS = free flow speed;  $v_p$  = demand flow rate (pc/h/ln).

**Figure 4-4 Identification of the critical speed from the speed-flow diagram**

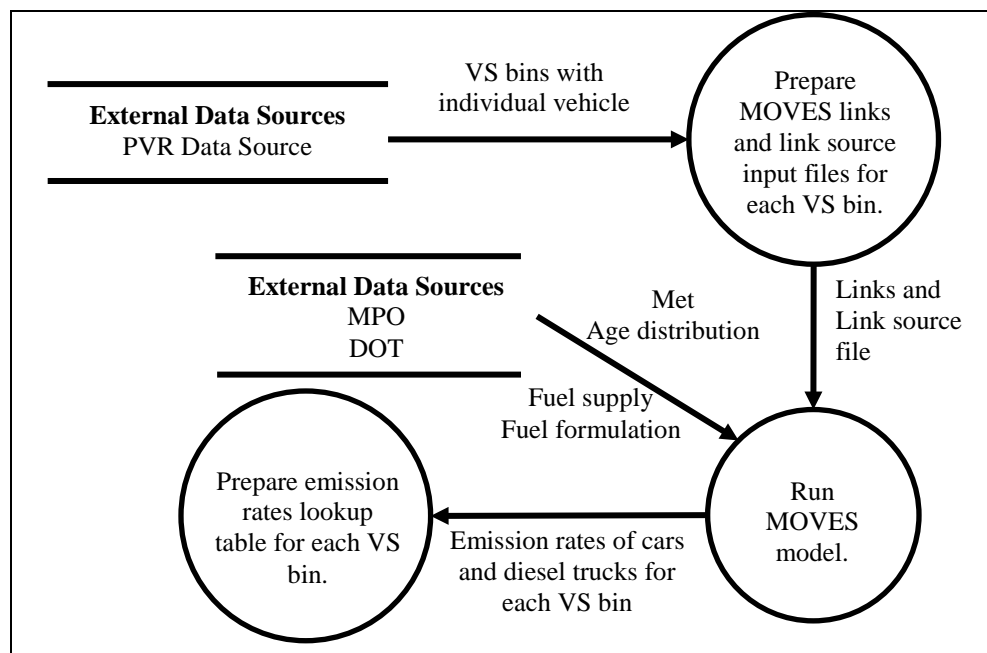


**Figure 4-5 Demonstration of the VS bin IDs**

#### 4.3.3 Preparation of Emission Rates Lookup Table

The emission rates lookup table stores average  $PM_{2.5}$  emission rates of passenger cars and diesel trucks for each VS bin. The data flows of preparing the emission rates lookup table are illustrated by Figure 4-6. The average emission rates of individual bins are calculated by using MOVES. First, the two MOVES traffic input files (i.e., link and link source files) are constructed based on the individual vehicle records linked to each VS bin. To setup the link file, a VS bin is counted as a MOVES link and the number of vehicles mapped to the VS bin is the link volume. Average speed is used to represent traffic activity in the link file and the average speed is obtained by calculating the mean value of the speed records of all vehicles mapped to the bin. The link source file records the fleet composition. The link source file is prepared by calculating the vehicle class distribution of vehicles that is mapped to each bin. Other MOVES inputs, including vehicle age distribution, meteorology data, fuel formulation and fuel supply data, can be acquired and obtained from the local MPO or DOT.

The major assumption for applying the emission rates look up table is that the emission rates of vehicles are very similar in the same VS bin and very different in different bins. If the assumption is valid, the differences of emission rates of vehicles in different VS bins would be statistically significant. To analyze the differences quantitatively, the emission rates of individual vehicles in each VS bin are calculated by using MOVES and the resulting emission rates are used in a hypothesis test. A vehicle's emission rate can be estimated by the MOVES model as long as the volume of the MOVES link is set as 1, the link speed as the vehicle's speed, and the link source as the vehicle's class. Other MOVES inputs for estimating the vehicle's emission factor are the same as those used to develop the emission rates lookup table. After the MOVES runs, the resulting emission rate samples are tested by using the Kolmogorov–Smirnov test (K-S test). In the K-S test, the null hypothesis is that the emission rate samples of two VS bins are from the same continuous distribution. If this underlying assumption is valid, the null hypothesis would be rejected at the 5% significance level (or 95% confidence level).



**Figure 4-6 Data flows for preparing emission rates lookup table**

*4.3.4 Estimation of Emission Factor Based on ATR Data*

A sample emission rates lookup table is shown by Table 4-5. To use the table, the traffic volume and truck volume need to be extracted from the ATR data. For example, if the traffic volume provided by the ATR data is 1300 vehicles/hour, Bin 7 represents free flow traffic and bin 12 represents congested traffic flow. The car emission rate is 5.765 milligram per vehicle per mile of bin 7 and 7.585 milligram per vehicle per mile of bin 12. The emission rate of individual passenger cars in the ATR data is the average of the two emission rates (6.675 milligrams per vehicle per mile). Similarly the emission rate of trucks is 0.1511 gram per vehicle per mile. Consequently, the emission factor calculated by the ATR data is  $6.675 \times (1300 - 80) / 1000 + 0.1511 \times 80 = 20.323$  grams per hour per mile.

**Table 4-5 Sample emission rates lookup table**

| Volume (veh/hour) | Bin ID <sup>a</sup> (free flow) | Car Rate <sup>b</sup> × 10 <sup>-3</sup> | Truck Rate | Bin ID (congested flow) | Car Rate × 10 <sup>-3</sup> | Truck Rate |
|-------------------|---------------------------------|--|------------|-------------------------|-----------------------------|------------|
| 0-200             | 1                               | 5.780                                    | 0.1286     | - <sup>c</sup>          | -                           | -          |
| 200-400           | 2                               | 5.767                                    | 0.1292     | -                       | -                           | -          |
| 400-600           | 3                               | 5.776                                    | 0.1296     | -                       | -                           | -          |
| 600-800           | 4                               | 5.785                                    | 0.1307     | -                       | -                           | -          |
| 800-1000          | 5                               | 5.895                                    | 0.1321     | -                       | -                           | -          |
| 1000-1200         | 6                               | 5.755                                    | 0.1296     | -                       | -                           | -          |
| 1200-1400         | 7                               | 5.765                                    | 0.1311     | 12                      | 7.585                       | 0.1711     |
| 1400-1600         | 8                               | 5.789                                    | 0.1324     | 13                      | 7.988                       | 0.1713     |
| 1600-1800         | 9                               | 5.837                                    | 0.1349     | 14                      | 7.618                       | 0.1639     |
| 1800-2000         | 10                              | 5.837                                    | 0.1349     | 15                      | 6.625                       | 0.1494     |
| > 2000            | 11                              | 5.837                                    | 0.1349     | -                       | -                           | -          |

Note: <sup>a</sup> the definition of bin ID can be found in Figure 4-5; <sup>b</sup> rate in g/vehicle/mile; <sup>c</sup> no data observed in this bin.

### 4.4 Estimation of Emission Factor Based on PVR Data Source

The methodology of estimating the emission factor based on PVR data source alone and on both PVR and micro-simulation data is shown by Figure 4-7. The PVR data source provides timestamp, speed, lane ID, number of axles and axle spacing observed at the monitoring station. The vehicle timestamp can be used to prepare traffic flow volume for MOVES link input file; the vehicle speed can be used to estimate the average speed; and the number of axles and axle spacing can be used to determine the vehicle class and then populate the link source input file. The PVR data source alone is able to provide the traffic inputs as required for the MOVES analysis. Since MOVES accepts three types of traffic activity inputs (i.e. average speed, link drive schedule and operating mode distribution) and the average speed provided by the PVR data contains the least detailed traffic activity information among the three types of inputs, there is room to improve the accuracy of the modeled emission factor if the link drive schedule or operating mode distribution input can be used to supplement the PVR data. It has been suggested from previous studies that the well calibrated micro-simulation model be viewed as a reliable source to provide the operating mode distribution (FHWA, 2004). The micro-simulation source is therefore selected to provide the supplemental operating mode distribution data for the PVR data source.

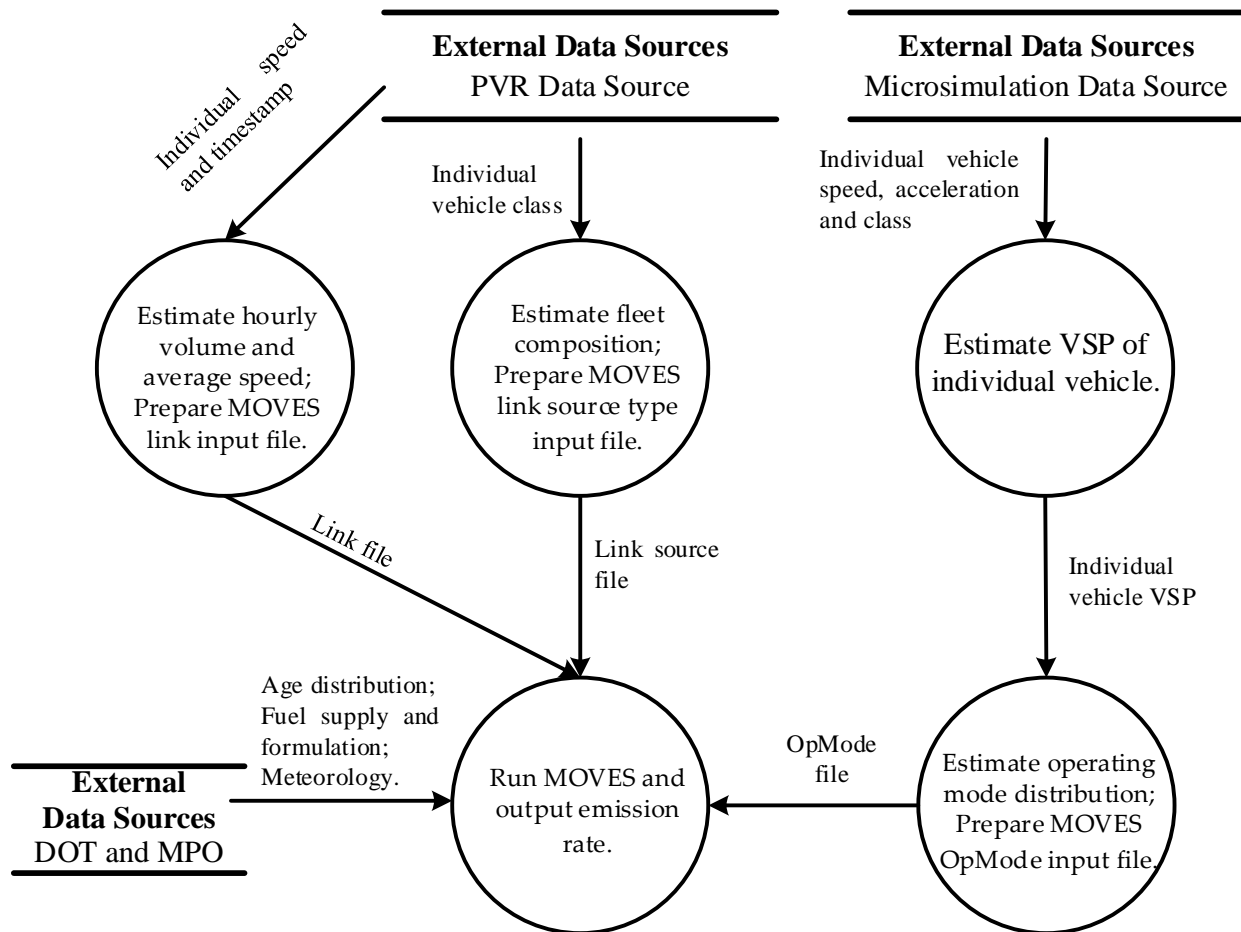


Figure 4-7 Data flows of estimating emission factor based on PVR data and/or micro-simulation data



The detailed steps on preparing the operating mode distribution based on the micro-simulation data will be discussed in Section 4.4.1. Steps of preparing the link source file based on PVR data are described in Section 4.4.2. The method for developing the link file based on average speed and link volume is straightforward and has been extensively discussed in the MOVES user manual (U.S. EPA, 2012). The related information is therefore not covered in this report. Users may refer to Section 2.3 in the MOVES user manual to find the detailed information.

#### Preparing Operating Mode Distribution Based on Micro-simulation Data

The sample micro-simulation data are shown in Table in Section 4.1. The simulation data are collected by a data collection point placed at a specified location in the simulation network and it works in a similar way as the loop detectors. Traffic data are collected in 1-second intervals. The detected vehicles are classified as passenger cars or trucks. If two or more vehicles are detected in an interval, the average speed and acceleration of these vehicles are stored in the output data table. An algorithm as shown by Table 4-6 is designed to prepare the operating mode distribution data based on the micro-simulation data source.

**Table 4-6 Algorithm for preparing operating mode distribution with micro-simulation data**

|   |
|---|
| <p><u>Step 1:</u> algorithm starts with the first record of the simulation data.</p> <p><u>Step 2:</u> obtain link ID of the record and identify MOVES link ID based on the link ID.</p> <p><u>Step 3:</u> obtain time from the record. If it is the end of an analysis time period, go to Step 8, otherwise go to Step 4.</p> <p><u>Step 4:</u> obtain speed and acceleration of passenger cars and trucks. Calculate vehicle specific power (VSP) by using Equation (4-1) and (4-2).</p> <p><u>Step 5:</u> determine operating mode IDs for passenger cars and trucks in the record based on vehicle speed and VSP according to Table 4-7.</p> <p><u>Step 6:</u> update the operating mode table (as shown by Table 4-8) based on the identified operating mode IDs and MOVES link ID.</p> <p><u>Step 7:</u> determine if the current record is the last record. If it is, go to Step 8, otherwise go to Step 2.</p> <p><u>Step 8:</u> calculate operating mode distribution based on the operating mode table.</p> |
|---|

$$VSP_{PC} = v(1.1a + 9.81\text{grade}(\%) + 0.132) + 3.02 \times 10^{-4} (v + v_w)^2 v \quad (0-0)$$

$$VSP_{HDV} = v(a + 9.81\sin(\text{grade}) + 0.092) + 0.00021v^3 \quad (0-0)$$

where,  $v$  is the speed (m/s);  $a$  is the acceleration ( $\text{m/s}^2$ ); and  $v_w$  is the headwind into the vehicle (m/s). Assume the grade of the study road is zero and the effect of the headwind is very small. The operating mode bin is identified based on vehicle's VSP and speed. The definition of operating mode bin is listed in Table 4-7.

The link source file records the fraction of different vehicle classes in each MOVES link. Since the MOVES manual only provides a qualitative definition of each source type (vehicle class), the MOVES vehicle classes are mapped to the FHWA vehicle classes (as shown by Table 4-9). The definition of FHWA vehicle classes, number of axles and the average length of each vehicle class are listed in Table 4-10.

To prepare the link source file, the number of axles and the length of each vehicle are firstly extracted from the PVR data source. Based on the axle and length information, the FHWA vehicle class ID can be identified for each vehicle of the PVR data. Finally the MOVES class is determined by using Table 4-10 and the link source file is prepared based on the MOVES class.

**Table 4-7 Definition of operating mode bins**

| VSP       | Instantaneous Speed |        |        |
|-----------|---------------------|--------|--------|
|           | 0-25 mph            | 15-50  | >50    |
| <0 KW/ton | Bin 11              | Bin 21 | N/A    |
| 0-3       | Bin 12              | Bin 22 | N/A    |
| 3-6       | Bin 13              | Bin 23 | N/A    |
| <6        | N/A                 | N/A    | Bin 33 |
| 6-9       | Bin 14              | Bin 24 | N/A    |
| 6-12      | N/A                 | N/A    | Bin 35 |
| 9-12      | Bin 15              | Bin 25 | N/A    |
| ≥12       | Bin 16              | N/A    | N/A    |
| 12-18     | N/A                 | Bin 27 | Bin 37 |
| 18-24     | N/A                 | Bin 28 | Bin 38 |
| 24-30     | N/A                 | Bin 29 | Bin 39 |
| ≥30       | N/A                 | Bin 30 | Bin 40 |

Note: Braking = bin 0; idle = bin 1.

**Table 4-8 Operating mode table**

| MOVES Link ID |       |           |       |
|---------------|-------|-----------|-------|
| OpMode ID     | Count | OpMode ID | Count |
| 0             | 0     | 25        | 0     |
| 1             | 0     | 27        | 0     |
| 11            | 0     | 28        | 0     |
| 12            | 0     | 29        | 0     |
| 13            | 0     | 30        | 0     |
| 14            | 0     | 33        | 0     |
| 15            | 0     | 35        | 0     |
| 16            | 0     | 37        | 0     |
| 21            | 0     | 38        | 0     |
| 22            | 0     | 39        | 0     |
| 23            | 0     | 40        | 0     |
| 24            | 0     |           |       |

*Preparing Link Source File based on PVR Data Source*

**Table 4-9 MOVES vehicle classification and FHWA vehicle classification**

| <b>MOVES Source Type ID</b> | <b>MOVES Source Type</b>      | <b>FHWA Vehicle Class ID</b> | <b>FHWA Vehicle Class</b>             |
|-----------------------------|-------------------------------|------------------------------|---------------------------------------|
| 11                          | Motorcycles                   | 1                            | Motorcycles                           |
| 21                          | Passenger cars                | 2                            | Passenger cars                        |
| 31                          | Passenger trucks              | 3                            | Other Two-Axle/Four Tire, Single Unit |
| 32                          | Light commercial trucks       | 3                            | Other Two-Axle/Four Tire, Single Unit |
| 41                          | Intercity buses               | 4                            | Buses                                 |
| 42                          | Transit buses                 | 4                            | Buses                                 |
| 43                          | School buses                  | 4                            | Buses                                 |
| 51                          | Refuse trucks                 | 5-10                         | Single Unit                           |
| 52                          | Single unit short-haul trucks | 5-10                         | Single Unit                           |
| 53                          | Single unit long-haul trucks  | 5-10                         | Single Unit                           |
| 54                          | Motor homes                   | 5-10                         | Single Unit                           |
| 61                          | Combination short-haul trucks | 11-13                        | Combination                           |
| 62                          | Combination long-haul trucks  | 11-13                        | Combination                           |

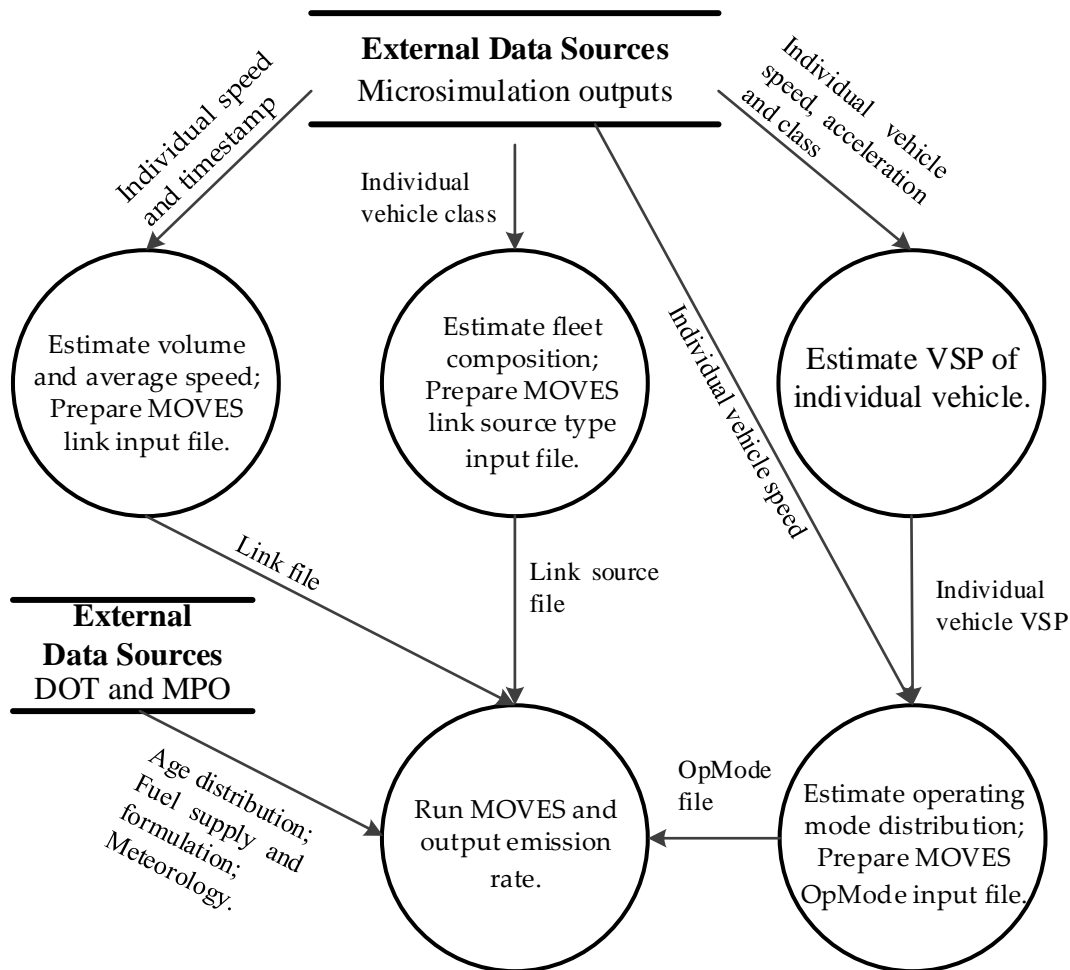
**Table 4-10 FHWA vehicle classification**

| <b>Categories</b>    | <b>FHWA Class ID</b> | <b>Description</b>    | <b>Definition</b>   | <b>Avg. Length (feet)</b> |
|----------------------|----------------------|-----------------------|---|---------------------------|
| Passenger carriers   | 1                    | Motorcycles           | 2 axles, 2 or 3 wheels.   | 5.38                      |
|                      | 2                    | Passenger cars        | 2 axles. Can have 1- or 2-axle trailers.                        | 15.33                     |
|                      | 3                    | Pickups, panels, vans | 2-axle, 4-tire single units.<br>Can have 1- or 2-axle trailers. | 18.32                     |
|                      | 4                    | Buses                 | 2- or 3-axle, full length.                                      | 38.06                     |
| Commodities Carriers | 5                    | Single-unit trucks    | 2-axle, 6-tire, (dual rear tires), single-unit trucks.          | 25.14                     |
|                      | 6                    | Single-unit trucks    | 3-axle, single-unit trucks.                                     | 24.68                     |
|                      | 7                    | Single-unit trucks    | 4 or more axle, single-unit trucks.                             | 31.58                     |
|                      | 8                    | Single-trailer trucks | 3- or 4-axle, single-trailer trucks.                            | 43.85                     |
|                      | 9                    | Single-trailer trucks | 5-axle, single-trailer trucks.                                  | 64.51                     |
|                      | 10                   | Single-trailer trucks | 6 or more axle, single-trailer trucks.                          | 63.50                     |
|                      | 11                   | Multi-trailer trucks  | 5 or less axle, multi-trailer trucks.                           | 68.76                     |
|                      | 12                   | Multi-trailer trucks  | 6-axle, multi-trailer trucks.                                   | 73.22                     |
|                      | 13                   | Multi-trailer trucks  | 7 or more axle, multi-trailer trucks.                           | 69.02                     |

## 4.5 Estimation of Emission Factor based on Micro-simulation Data Source

### 4.5.1 Method Framework

The micro-simulation data source provides timestamp, location, speed, acceleration and class of individual vehicles in the simulated roadway network. The data flows of estimating emission factors based on the micro-simulation data are shown in Figure 4-8. The preparation of link, link source and operating mode distribution files for MOVES has been discussed in Section 4.4. As mentioned in Section 4.2, the simulation model needs to be calibrated and validated prior to generating traffic data source from running the simulation model. The methodology for calibrating and validating a simulation model is discussed in Section 4.5.2.

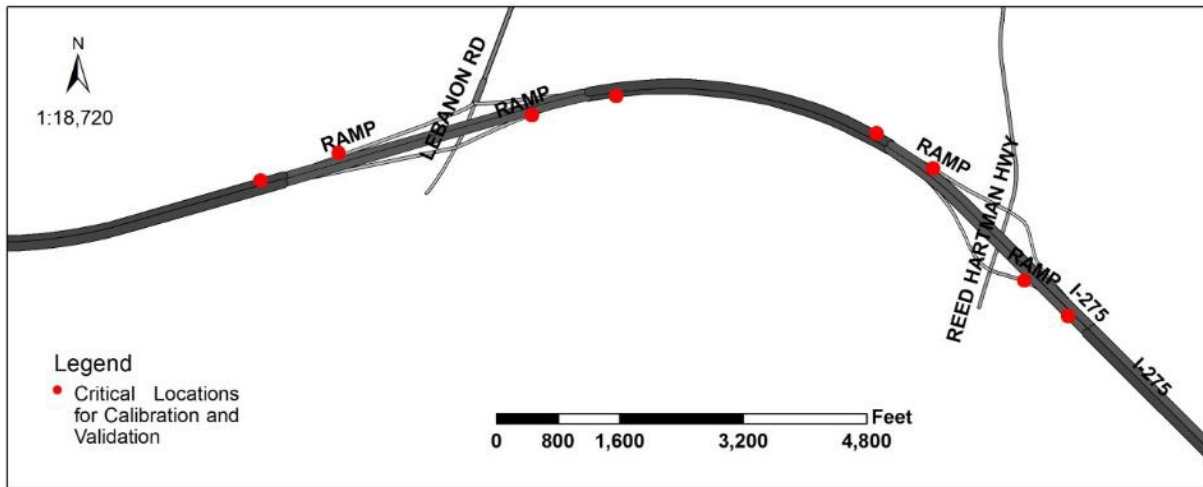


**Figure 4-8 Data flows of estimating emission factor based on micro-simulation data**

### 4.5.2 Calibrating and Validating Micro-simulation Models

A microscopic traffic simulation model must be calibrated and validated before it is used to provide traffic data. Two major steps are involved in the model calibration (as shown by Table 4-11). The objective of calibration is to minimize the deviation between the observed traffic data and corresponding simulated traffic data at selected critical locations. Critical locations are

referred to the key points on the concerned roadway network which could impact the whole road network, such as bottleneck locations and merge points (Columbia River Crossing, 2006). For example, the critical locations for a freeway study area are demonstrated by Figure 4-9.



**Figure 4-9 Critical locations for calibration and validation**

**Table 4-11 Steps of calibration**

**Step 1, calibrating capacity:**

- Obtain the capacity of the study site by using the speed-flow diagram prepared based on the PVR data.
- Create a bottleneck in the simulation model and measure the modeling capacity downstream of the bottleneck.
- Adjust simulation parameters to minimize the difference between the modeling capacity and the observed capacity.

**Step 2, calibrating speed distribution:**

- After the capacity calibration has been passed, run the simulation model with the real-world traffic input.
- Measuring speed data in the simulation network. The data collection point should be the same point where the real-world data are collected.
- Adjust simulation parameters to minimize the difference between the modeling speed and the observed speed.

The GEH statistics approach is used to represent the validity of a model. The GHE statistic for a link is computed by using the following equation:

$$GEH = \sqrt{\frac{2(P_s - P_o)^2}{P_s + P_o}} \quad (0-0)$$

where,  $P_s$  is the modeled traffic parameter, and  $P_o$  is the observed traffic parameter. A simulation model passes the validation if the GEH statistic is less than 5, and the modeled capacity and speed samples are within  $\pm 15\%$  of the measured data points in more than 85% cases (FHWA, 2004).

## CHAPTER 5 : EVALUATION OF AVAILABLE TRAFFIC DATA SOURCES

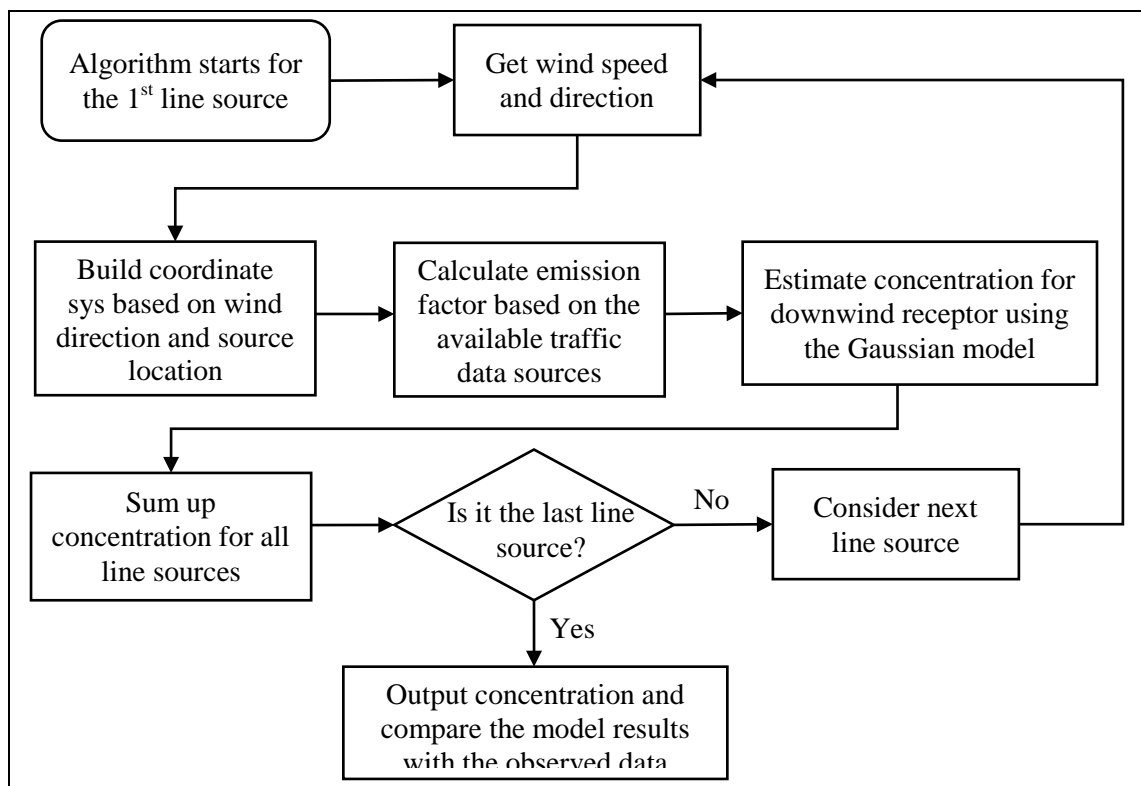
In this chapter, the applicability of the available traffic data sources is evaluated in details. The primary purpose of the evaluation is to clarify if the traffic data sources identified in Chapter 4 could be based to generate inputs to the MOVES for estimating  $PM_{2.5}$  emission factors and dispersion model for further ambient concentration estimation with acceptable accuracy by comparing with the on-site monitored  $PM_{2.5}$  concentration level. If a positive result is found through the evaluation, it is then feasible to apply the available traffic data sources in the  $PM_{2.5}$  conformity analysis. To this end, the ATR, PVR and micro-simulation data are collected at a case study site (i.e. the Interstate 275, or I-275 in the Greater Cincinnati area, Ohio), and these sources are used to estimate the emission factor for road links located at the site by using the method presented in Chapter 4. The estimated emission factor is then utilized as inputs for the Gaussian plume dispersion model adapted by AERMOD. Consequently, the roadside concentration of the study site is estimated by using the dispersion model. On the other hand, the concentration is monitored at the study site and the modeled concentration is compared with the observed data.

The objective of the comparison analysis is two-fold: 1) to determine if it is feasible to apply the available data sources in the conformity analysis through the methodology presented in Chapter 4; and 2) to identify the accuracy impact of applying different data sources on the concentration estimation. The accuracy of the data sources are revealed through the application of four statistical parameters (i.e. index of agreement, normalized mean squared error, the fractional bias and the factor of two, which will be discussed in details in Section 5.3.2). In Section 5.1, the methodological framework for conducting the evaluation, including the line emission source characterization and the application of the dispersion model, is described in detail. The data collection for the case study is introduced in Section 5.2 and the evaluation results are presented and discussed in Section 5.3.

### 5.1 Evaluation Framework

The framework for conducting the evaluation is illustrated by Figure 5-1. As indicated by the framework, the study road segment will be characterized first as line emission sources. And then, a coordinate system is determined based on the geometry features of the emission source and the wind condition of a concerned analysis interval. Next, the emission factor is estimated based on the available traffic data sources using the methods presented in Sections 4.3 through 4.5, and the estimated emission factor is input in the Gaussian plume dispersion model to calculate the roadside concentration. Finally, the modeled concentration is compared with the observed data.

In Section 5.1.1, the method for characterizing line emission sources is described. The Gaussian plume dispersion model is presented in Section 5.1.2.



**Figure 5-1 Framework of evaluating the applicability of the available traffic data sources**

### 5.1.1 Characterizing Line Emission Sources

The concept of line emission source characterization method is shown by Figure 5-2. This method is developed based on the CALINE4 model's finite line source characterization method (US California Department of Transportation, 1986). In the emission source characterization method, a concerned highway segment is divided into multiple elements. The status of traffic activity (e.g., speed and acceleration) within each element should be spatially static so that the element can be assumed to be a homogeneous emission source. Since traffic flow status usually varies with different travel lanes, a highway segment is first divided so that each lane is modeled separately. Furthermore, the highway lanes are divided into short parts in the direction of the traffic flow. It is assumed that the operation status of a vehicle will remain unchanging when it travels within each defined short part of the highway lanes. After dividing the highway segment across the lanes and along the direction of the traffic flow, it is safe to apply the constant emission rate to the divided elements of the highway segment.

In the presented line emission source characterization method, individual travel lanes are divided into a series of elements and the element length increases as the distance from the element to the study downwind receptor becomes larger (as shown by Figure 5-2). The two elements (i.e.  $E_1$  and  $E_2$  in Figure 5-2) closest to the receptor are square elements with sides equal to the width of the source. The lengths for other elements are calculated by using Equation (5-1). Each element of a road segment is modeled as an equivalent line source that is perpendicular to the wind direction and centered at the element center. As shown by the inset of

Figure 5-2, the length of an equivalent line source is determined by its projection on the axis perpendicular to the wind direction.

$$EL = W \times Base^{NE-1} \quad (0-0)$$

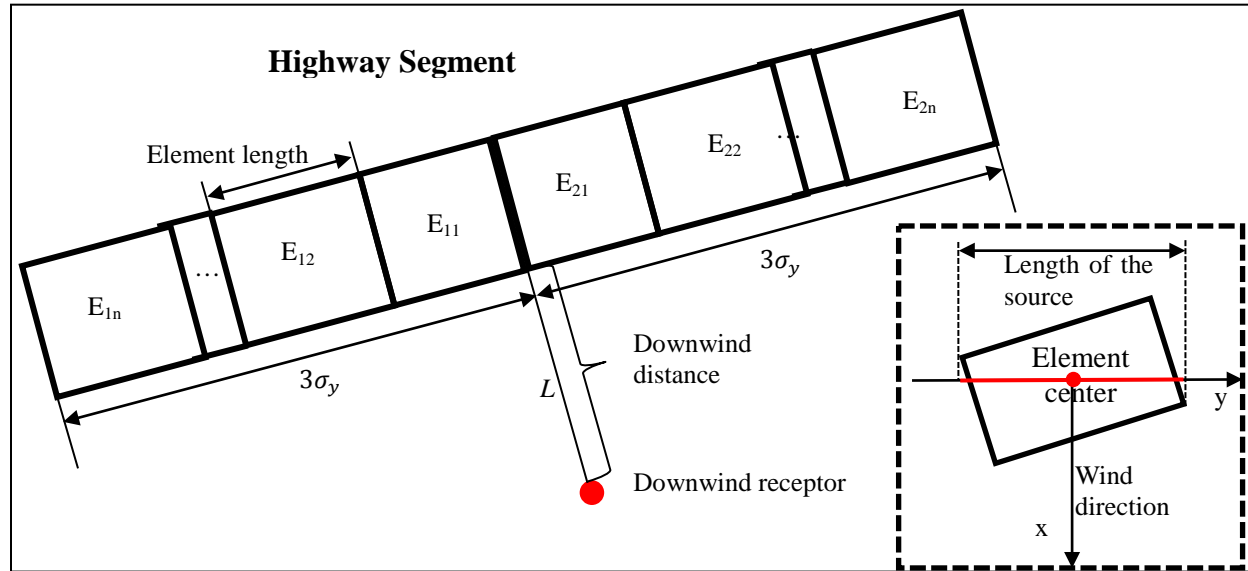
where,  $EL$  = element length, m;

$W$  = lane width, m;

$NE$  = element number;

$Base$  = element growth factor,  $Base = 1.1 + \varphi^3 / 2.5 \times 10^5$ ; and

$\varphi$  = angle between wind and the road link, degrees.

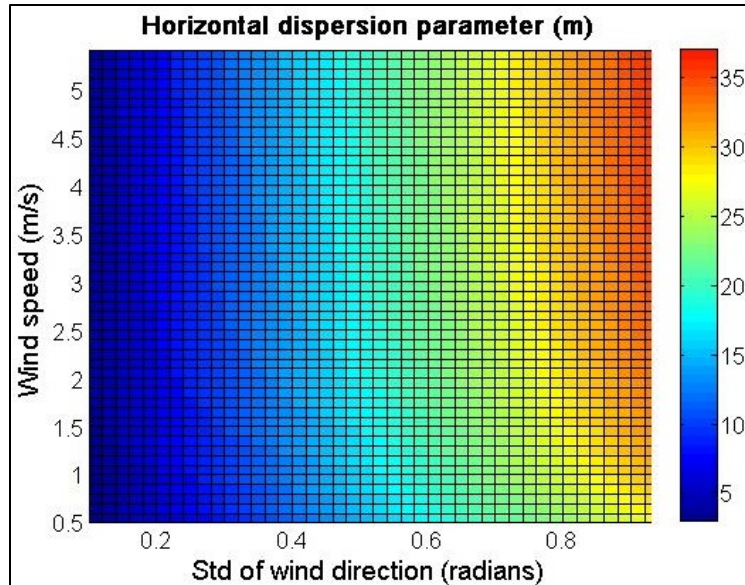


**Figure 5-2 Characterizing a highway segment into elements**

For a defined element, if the distance between an element's short sides and the line  $L$  (as shown in Figure 5-2) is less than a certain distance (which is defined as a critical distance after it is quantified), the element is included in estimating the downwind receptor's concentration. The rest elements of the modeled highway segment are neglected since their contributions to the total concentration are very small. The threshold distance is determined according to the horizontal dispersion parameter  $\sigma_y$  and equal to  $3\sigma_y$ . In practice, however,  $\sigma_y$  is a variable determined by the downwind distance of the study receptor, wind speed and standard deviation of wind speed in an analysis interval. The variation of  $\sigma_y$  makes the number of considered elements changes in every analysis interval. In order to avoid repeated calculations of the number of elements in every interval, the largest possible  $\sigma_y$  is identified in the presented methodology for a study site so that the critical distance considered in the modeling can be determined permanently.

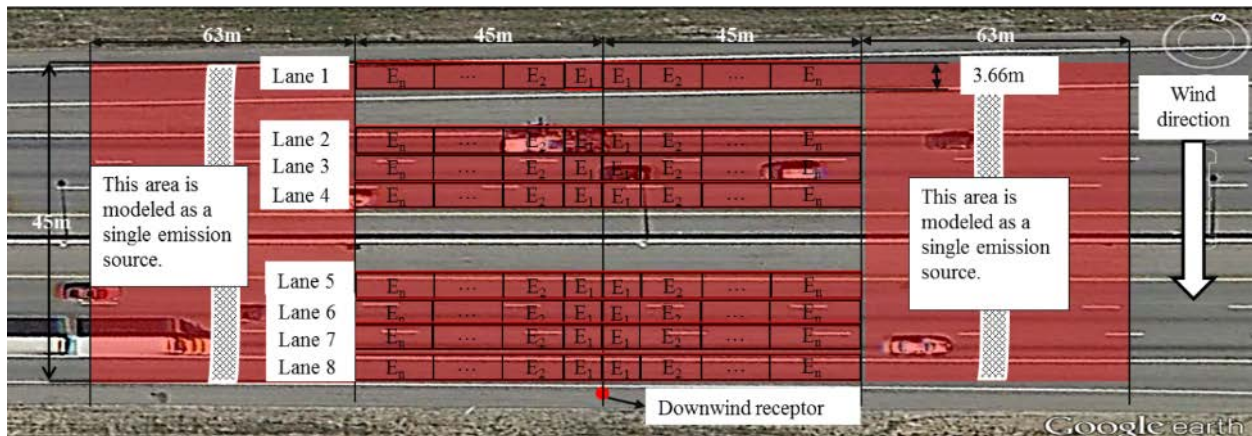
The maximum  $\sigma_y$  is observed when the wind direction is perpendicular to the highway segment. Figure 5-3 shows the change of  $\sigma_y$  with the change of the wind speed and the standard deviation of wind direction. For example, assume that the observed wind speed is than 5 m/s and the standard deviation of wind direction in radians is 0.90. In such a case, the maximum  $\sigma_y$  is about 36 meters, and thus the highway segment considered at one side of the receptor should have a length of 108 meters.





**Figure 5-3 Change of  $\sigma_y$  with wind speed and standard deviation of wind direction**

The output of the presented emission source characterization method is demonstrated by Figure 5-4. In Figure 5-4, the width of the study highway segment is 45 meters. The presented line emission source characterization method is used for the two square areas that are adjacent to the downwind receptor, because the two areas have the major contribution to the concentration of the downwind receptor (U.S. EPA, 1986). The remaining area of the study highway segment is modeled as single line emission source so that the efficiency for the dispersion model to simulate the study site can be improved, comparing to the case that the entire study area is totally characterized by the presented method.



**Figure 5-4 New line emission sources characterization method**

### 5.1.2 The Gaussian Plume Dispersion Model

The Gaussian plume dispersion model is used to estimate roadside concentration based on the emission factors calculated by using the available traffic data sources. The Gaussian plume

dispersion model adapted in AERMOD, CALINE4 and CAL3QHR is selected and the model formulation is expressed by Equation (5-2).

$$C = \frac{q}{2\pi u \sigma_y \sigma_z} \left[ \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \right] \left\{ \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right] \right\} \quad (0-0)$$

where,  $C$  = concentration of receptor at  $(x, y, z)$ ,  $\text{g}/\text{m}^3$ ;

$q$  = emission factor,  $\text{g}/\text{s}$ ;  $u$  = wind speed,  $\text{m}/\text{s}$ ;

$H$  = source height,  $\text{m}$ ; and

$\sigma_y, \sigma_z$  = horizontal and vertical dispersion parameters,  $\text{m}$ .

In order to estimate  $\sigma_z$ , the residence time  $TR$  for a parcel of air resides in the turbulent mixing zone (the space above the road, in seconds) is calculated using Equation (5-3).

$$C = \frac{q}{2\pi u \sigma_y \sigma_z} \left[ \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \right] \left\{ \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right] \right\} \quad (0-0)$$

$$TR = \begin{cases} W2 / u \cdot \sin \theta & \theta \geq 45^\circ \\ W2 / u \cdot \sin 45^\circ & \theta < 45^\circ \end{cases} \quad (0-0)$$

where,  $W2$  = half width of the line emission source,  $\text{m}$ ; and

$\theta$  = angle between the wind direction and road link, degree.

When the downwind distance  $d$  ( $\text{m}$ ) of a receptor from the emission source is less than  $W_{mix}$  ( $\text{m}$ ),  $\sigma_z$  is equal to  $\sigma_{zi}$ :

$$\sigma_{zi} = 1.5 + TR / 10 \quad (0-0)$$

$$W_{mix} = \begin{cases} W2 / \sin \theta & \theta \geq 45^\circ \\ W2 / \sin 45^\circ & \theta < 45^\circ \end{cases} \quad (0-0)$$

When  $d$  is larger than  $W_{mix}$ ,  $\sigma_z$  is calculated using Equation (5-6):

$$\sigma_z = \sigma_{zi} \cdot d^{(\sigma_{zi}/m)} \quad (0-0)$$

where,  $\sigma_{zm}$  is the vertical dispersion parameter at  $d$  is 10000  $\text{m}$  and estimated using Equation (5-7).

$$m = \exp\left(\frac{\ln 10^4 \cdot \ln \sigma_{zi}}{\ln W_{mix}}\right) \quad (0-0)$$

The horizontal dispersion parameter  $\sigma_y$  can be calculated by Equation (5-8):

$$\sigma_y = \sigma_\varphi \cdot d \cdot \left[ 1 + 0.9 \cdot \left( \frac{TT}{TI} \right)^{0.5} \right]^{-1} \quad (0-0)$$

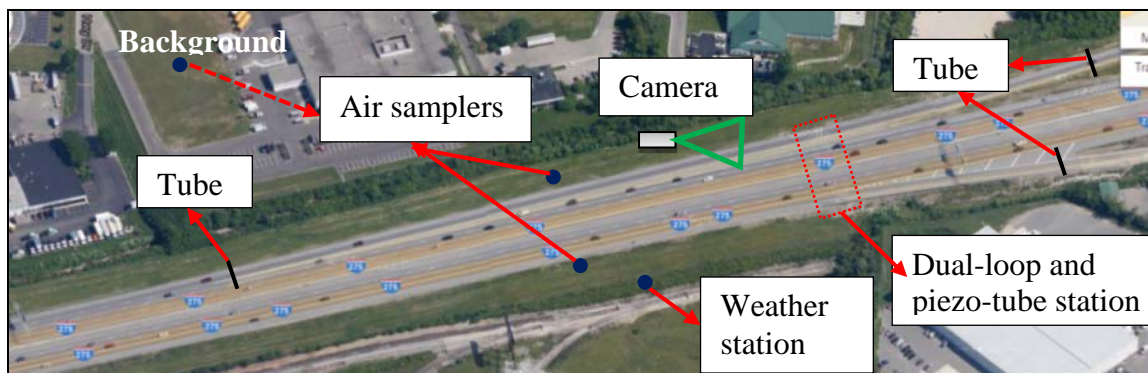
where,  $\sigma_\varphi$  = standard distribution of historical horizontal wind angle, radians;

$TT = d/u$ ;  $TI$  = diffusion time and is equal to 300 seconds.

## 5.2 Evaluation Data

The applicability of the ATR, PVR and micro-simulation data sources is evaluated by using the sample data collected at a freeway segment of the Interstate 275 (or I-275) in the Greater Cincinnati area, Ohio. Three datasets, namely roadside  $\text{PM}_{2.5}$  concentration data, meteorology data, and traffic data, were collected at the study site. Data collection was performed on clear

weekdays between 7:00 am to 7:00 pm from October 15<sup>th</sup> to 29<sup>th</sup>, 2012. About 60 hours of traffic data, roadside and background PM<sub>2.5</sub> concentration data, and meteorology data were used in this study. Figure 5-5 shows the data collection site and on site layout plan of the data collection equipment.



**Figure 5-5 Data collection site and equipment deployment**

Minute-by-minute PM<sub>2.5</sub> mass concentrations were measured by using two beta ray attenuation continuous air samplers (E-BAM by Met One Instruments) placed at both freeway shoulders. Since concentrations observed at receptors downwind of emission sources are of more importance, the application of the two air samplers ensures that the downwind roadside concentrations can be collected at all wind conditions. The output datasets from the samplers are then combined so that the downwind concentration is summarized in one data table. Since there are no other major PM<sub>2.5</sub> sources near the study site, it is assumed that the measured concentration is mainly contributed by the roadway traffic activities. Given the short source-to-receptor travel distance and travel time, chemical reactions and the resulting secondary PM<sub>2.5</sub> is not considered in this study. The contribution of traffic to the PM<sub>2.5</sub> emission is determined by subtracting the concurrent background value from each downwind PM<sub>2.5</sub> concentration measurements. The background PM<sub>2.5</sub> concentration data were collected at a site in the nearby surrounding residential area about one (1) kilometer north away from the selected I-275 monitoring site by using the same type of air sampler. Since the temporal variation of the background concentration is much less than that of the near-road observations, the background datasets are averaged into 1-hour interval.

Traffic data for the I-275 freeway were collected by a permanent traffic monitoring station equipped with dual-loop detectors and piezo-tube sensors. Traffic information extracted from the station, including individual vehicle's timestamp, speed and number of axles, forms the PVR data source. Also the PVR data have been aggregated to construct the ATR dataset. In addition, the same traffic data for the westbound on ramp and eastbound off ramp were collected by portable tube stations and video cameras. The peak hour volume on a typical weekday of the observed freeway is about 10,000 vehicles per hour and the truck traffic is approximately 6% of the total daily traffic volume. Meteorology data were collected by a portable weather station about 30 meters south of the study highway segment. Minute-by-minute temperature, relative humidity, wind speed and wind direction were recorded by the weather station.

### 5.3 Evaluation Results and Discussions

The roadside concentration estimated based on the available traffic data sources is compared with the observed data collected at the study site mentioned in Section 5.2. The compared results are discussed in this section. As mentioned in Section 4.2.3, the emission rates lookup table prepared based on the PVR data needs to be validated before it is used to supplement the ATR data source to calculate the emission factor. The validation results are also presented in this section.

#### 5.3.1 Validation of Emission Rates Lookup Table

The VS bins and the individual vehicle record datasets linked to each VS bin are developed based on the PVR traffic by using the method described in Section 4.2.2. The VS bins and individual vehicle records are then applied to create the emission rates lookup table through using the method described in Section 4.2.3. The average emission rates of passenger cars and diesel trucks in each VS bin are shown by Table 5-1.

**Table 5-1 Emission rates lookup table of passenger cars and trucks in each VS bin (g/mile)**

| <b>Bin ID</b> | <b>Car Rate<br/><math>\times 10^{-3}</math></b> | <b>Truck Rate</b> | <b>Bin ID</b> | <b>Car Rate<br/><math>\times 10^{-3}</math></b> | <b>Truck Rate</b> |
|---------------|---|-------------------|---------------|---|-------------------|
| <b>1</b>      | 5.780   | 0.1286            | 9             | 5.837   | 0.1349            |
| <b>2</b>      | 5.767   | 0.1292            | 10            | 5.837   | 0.1349            |
| <b>3</b>      | 5.776   | 0.1296            | 11            | 5.837   | 0.1349            |
| <b>4</b>      | 5.785   | 0.1307            | 12            | 7.585   | 0.1711            |
| <b>5</b>      | 5.895   | 0.1321            | 13            | 7.988   | 0.1713            |
| <b>6</b>      | 5.755   | 0.1296            | 14            | 7.618   | 0.1639            |
| <b>7</b>      | 5.765   | 0.1311            | 15            | 6.625   | 0.1494            |
| <b>8</b>      | 5.789   | 0.1324            |               |   |                   |

Note: the VS bins that represent free flow traffic flow status are shown in the left side of the table; the VS bins that represent congested traffic flow status are shown in the right side of the table.

As mentioned in Section 4.2.3, the emission rates in different VS bins will be statistically different if the emission rates lookup table is able to accurately distinguish the emission rate samples of each VS bin. To analyze the hypothesis, the K-S test has been performed at 5% significance level for emission rate samples between individual two bins. If the p value of the K-S test is lower than 0.05, it indicates that the emission rate samples of the two bins are statistically different. In Table 5-2, the test results of car emission rates are shown above the gray cells and the results of truck emission rates are placed below the gray cells. The bold values imply that the emission rates of two bins are not significantly different. It can be found that the emission rates in different bins are significantly different in most cases. The insignificant cases are often observed between two neighboring bins (i.e., between bin 1 and bin 2, bin 3 and bin 4). One reason of the insignificant difference is that the volume interval (200 vph) used to characterize the bins could be too small to distinguish the traffic flow status between some bins. Vehicles in these bins are in similar operation status and thus their emission rates are similar. Nonetheless, the presented method still adapts 200 vehicles per hour as the binning interval since the binning interval is good for most cases.

**Table 5-2 K-S test results of emission rates from different VS bins**

| Bin ID | 1           | 2    | 3           | 4    | 5           | 6           | 7           | 8           | 9           | 10          | 11   | 12          | 13          | 14          | 15          |
|--------|-------------|------|-------------|------|-------------|-------------|-------------|-------------|-------------|-------------|------|-------------|-------------|-------------|-------------|
| 1      |             | 0.00 | 0.04        | 0.00 | 0.01        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.02        |
| 2      | <b>0.59</b> |      | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        |
| 3      | 0.01        | 0.01 |             | 0.01 | <b>0.07</b> | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        |
| 4      | 0.00        | 0.00 | <b>0.30</b> |      | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.01        |
| 5      | 0.00        | 0.00 | <b>0.29</b> | 0.02 |             | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.02        |
| 6      | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        |             | <b>0.09</b> | 0.00        | 0.00        | 0.01        | 0.02 | 0.02        | 0.00        | 0.00        | 0.00        |
| 7      | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.03        |             | 0.02        | 0.00        | 0.01        | 0.01 | 0.01        | 0.00        | 0.00        | 0.00        |
| 8      | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.00        | <b>0.09</b> |             | <b>0.26</b> | <b>0.12</b> | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        |
| 9      | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.00        | 0.03        | <b>0.56</b> |             | <b>0.39</b> | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        |
| 10     | 0.01        | 0.00 | 0.02        | 0.05 | 0.03        | <b>0.26</b> | <b>0.30</b> | 0.08        | 0.05        |             | 0.01 | 0.01        | 0.00        | 0.00        | 0.00        |
| 11     | 0.01        | 0.00 | 0.02        | 0.05 | 0.03        | <b>0.26</b> | <b>0.30</b> | 0.08        | 0.05        | 0.05        |      | 0.01        | 0.00        | 0.00        | 0.00        |
| 12     | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 |             | 0.00        | 0.01        | <b>0.24</b> |
| 13     | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        |             | <b>0.81</b> | 0.03        |
| 14     | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | 0.00        | <b>0.54</b> |             | <b>0.10</b> |
| 15     | 0.00        | 0.00 | 0.00        | 0.00 | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00        | 0.00 | <b>0.13</b> | <b>0.15</b> | <b>0.27</b> |             |

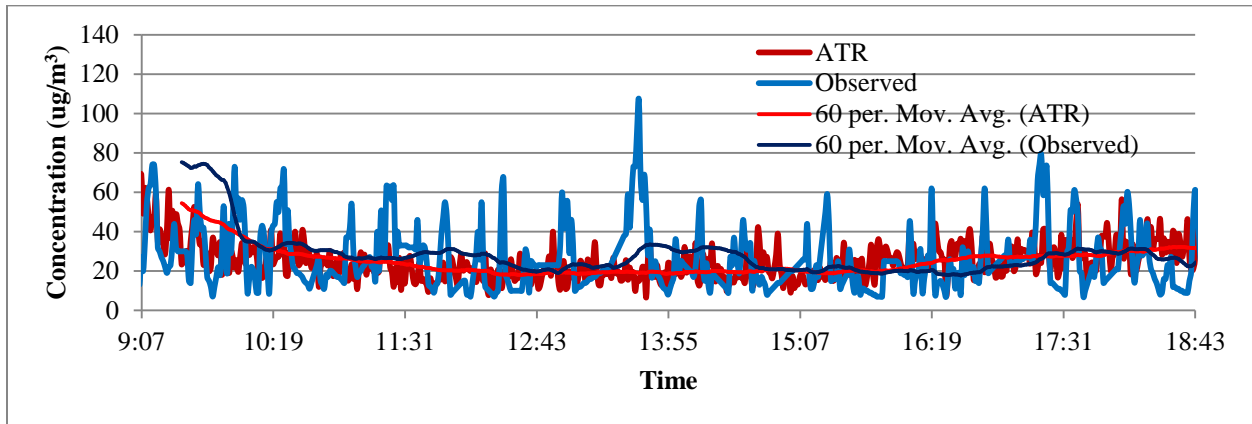
Note: the test results of car emission rates in different VS bins are shown above the gray cells; the test results of truck emission rates in different VS bins are shown below the gray cells.

### 5.3.2 Evaluation of Applicability of Traffic Data Sources

The sample datasets of the available data sources collected at the study site are input into the evaluation algorithm presented in Section 5.1. The evaluation results are discussed in this section. First, the modeled concentrations are plotted in the time-concentration diagram and compared with the observed samples. Specifically, the diagrams constructed based on data collected on October 24<sup>th</sup>, 2012 are demonstrated in the following figures. The empirical comparison can reveal the similarity of temporal variations between the modeled and observed roadside PM<sub>2.5</sub> concentration data. Next, statistical parameters are used to quantify the accuracy of the predicted concentration. The accuracy difference of applying the ATR, PVR and micro-simulation data sources can be analyzed by studying the scores of the statistical parameters.

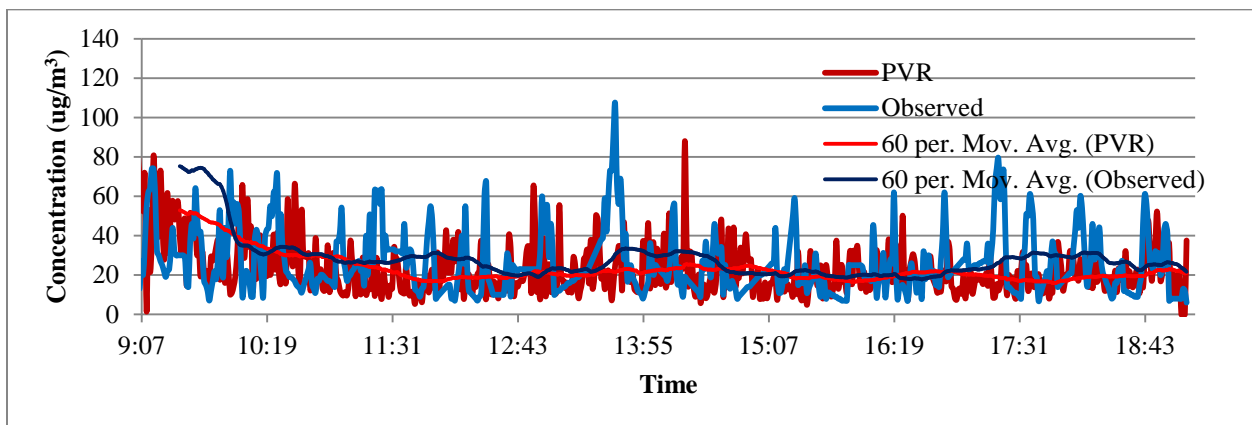
The 1-minute interval concentrations estimated based on the ATR data are presented by Figure 5-6. In addition, the 60-minute moving average curves of the modeled and observed datasets are also calculated and illustrated in Figure 5-6 for the hourly concentration is used to determine whether a project area conforms to the NAAQS or not in the PM<sub>2.5</sub> conformity analysis. It can be noted from the Figure 5-6 that the hourly trends of the two datasets (as shown by the moving average curves) are consistent. There is a slightly underestimation from the modeled results. The consistency of the modeled and observed hourly concentrations indicates that the ATR data source is accurate enough to provide the traffic data as needed in the PM<sub>2.5</sub> conformity analysis. On the other hand, the modeled data cannot accurately reproduce peaks and valleys of the PM<sub>2.5</sub> concentration as compared to the real-world 1-minute interval data. The inconsistency of the modeled and observed curves exists because only 1-hour or 15-minute aggregated traffic parameters are recorded in the ATR data source. Without detailed traffic activity inputs, the fine changes of the emission factor could not be estimated by the emission

model and thus the estimated concentration is not as accurate as the observed sample in such a short temporal resolution.



**Figure 5-6 Concentration results based on ATR data source**

The 1-minute interval curve and 60-minute moving average curve estimated based on the PVR data source are displayed by Figure 5-7. Since individual vehicle records are stored in the PVR data source, the change of traffic flow rate and average speed can be identified in 1-minute interval. As a result, the peaks and valleys of the roadside concentration are well represented by the results estimated based on the PVR data. The trends of PVR results and observed samples are also very similar. That indicates the feasibility of applying the PVR data in the  $PM_{2.5}$  conformity analysis.

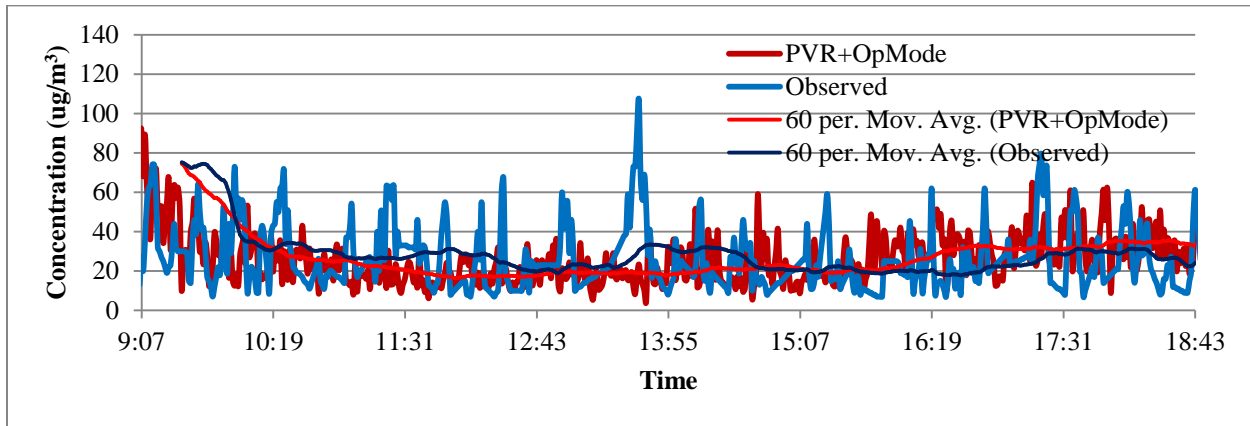


**Figure 5-7 Concentration results based on PVR data source**

As demonstrated by Figure 5-8, the accuracy of the modeled roadside concentration can be improved if the operating mode distribution provided by the micro-simulation data is used to supplement the PVR data. Such an accuracy improvement is clearly indicated by the moving average curve of the modeled data. For example, the moving average curves of the modeled and observed data are more consistent during 9:00 am to 10:30 am and 16:00 pm to 18:30 pm in Figure 5-8 than Figure 5-7. In addition, it is likely that during the morning and afternoon peak

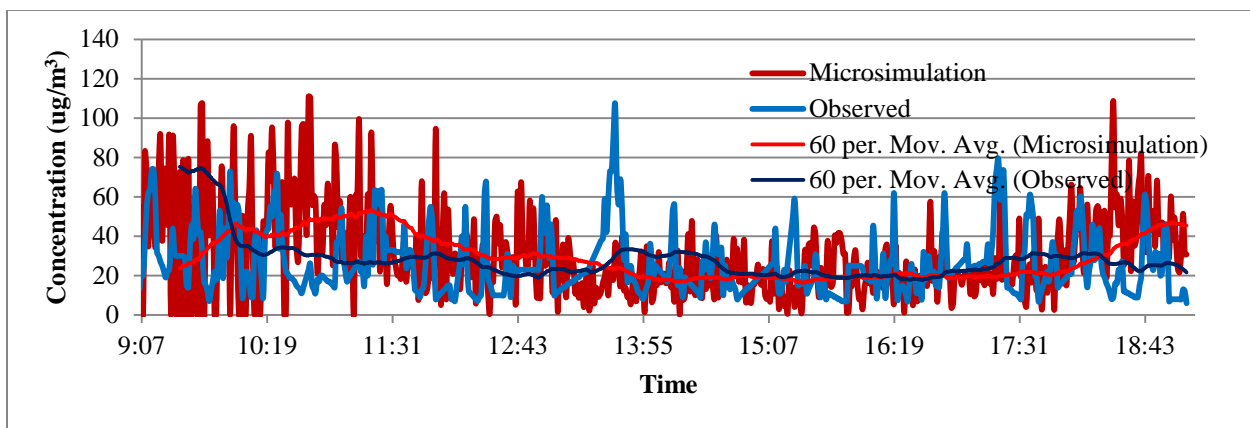


hour traffic activities are the dominant contributor to the concentration. The change of traffic flow can explain the change of concentration.



**Figure 5-8 Concentration results based on PVR data source and Operating mode distribution provided by micro-simulation data source**

The roadside concentration estimated based on the micro-simulation data source is shown by Figure 5-9. During the morning and afternoon peak hours, there are some overestimations in the modeled results. During the morning hours, the 1-minute interval variation of the modeled data is much more intensive than the observed data. As shown by Figure 5-6 through Figure 5-9, none of the traffic data sources is able to help reproduce the large concentration peaks as observed around 14:00 pm. The traffic video data taken at that time are investigated but no traffic related reason is identified. Therefore, the large peak value appeared around 14:00 pm may be caused by other non-traffic parameters.



**Figure 5-9 Concentration results based on micro-simulation data source**

In addition to the qualitative comparison as shown by Figure 5-6 through Figure 5-9, the accuracy of the modeled results is analyzed by using four statistical parameters. The four statistical parameters are: index of agreement (IA), normalized mean squared error (NMSE), the fractional bias (FB) and the factor of two ( $F_2$ ). These parameters are defined in Equations (5-10) through (5-13). IA ranges from 0 to 1. An IA score of 0 suggests little or no agreement among

modeled and observed data. An IA score of 1 suggests uniform and consistent match between the two datasets. NMSE measures the error of the modeled results and has an ideal value of 0. FB varies between -2 and 2 and has an ideal value of 0 for an ideal model.  $F_2$  has an ideal value of 1 for an ideal model. Typical scores of these parameters are surveyed from literature and are listed in Table 5-3.

$$IA = 1 - \frac{\overline{(C_{pred} - C_{obs})^2}}{\left( \left| \overline{C_{pred}} - \overline{C_{obs}} \right| - \left| \overline{C_{obs}} - \overline{C_{obs}} \right| \right)^2} \quad (0-0)$$

$$NMSE = \frac{\overline{(C_{pred} - C_{obs})^2}}{\overline{C_{pred}} \cdot \overline{C_{obs}}} \quad (0-0)$$

$$FB = \frac{2 \cdot (\overline{C_{pred}} - \overline{C_{obs}})}{\overline{C_{pred}} + \overline{C_{obs}}} \quad (0-0)$$

$$F_2 \text{ is the fraction of data for which } 0.5 < \frac{C_{pred}}{C_{obs}} < 2 \quad (0-0)$$

where,  $C_{pred}$  = predicted concentrations,  $g/m^3$ ; and  
 $C_{obs}$  = observed concentrations,  $g/m^3$ .

**Table 5-3 Typical scores of statistical parameters**

| Study                           | Model                | Compound            | Time Interval | IA   | NMSE | FB    | $F_2$ |
|---------------------------------|----------------------|---------------------|---------------|------|------|-------|-------|
| Ganguly and Broderick (2010)    | GFLSM <sup>1</sup>   | NOx                 | Hourly        | 0.52 | 0.92 | 0.16  | 0.8   |
|                                 | HM <sup>2</sup>      | NOx                 | Hourly        | 0.57 | 0.90 | 0.00  | 0.80  |
|                                 | IITLS <sup>3</sup>   | NOx                 | Hourly        | 0.69 | 1.24 | 0.08  | N/A   |
| Kumar et al. (2008)             | Kumar's Model        | N <sub>10-300</sub> | Half-hour     | N/A  | N/A  | -0.02 | 0.53  |
|                                 | Kumar's Model        | N <sub>10-30</sub>  | Half-hour     | N/A  | N/A  | -0.01 | 0.54  |
| Broderick and O'Donoghue (2007) | CALINE4 <sup>4</sup> | n-Pentance          | Daily         | N/A  | 1.3  | 0.13  | 0.50  |
|                                 | CALINE4              | Iso-pentance        | Daily         | N/A  | 3.2  | 0.44  | 0.45  |
|                                 | CALINE4              | Ethane              | Daily         | N/A  | 0.4  | 0.02  | 0.75  |
|                                 | CALINE4              | Propene             | Daily         | N/A  | 0.6  | 0.07  | 0.70  |
|                                 | CALINE4              | 1,3-Butadiene       | Daily         | N/A  | 0.8  | 0.03  | 0.55  |
|                                 | CALINE4              | Acetylene           | Daily         | N/A  | 0.6  | 0.22  | 0.55  |
|                                 | CALINE4              | Benzene             | Daily         | N/A  | 0.3  | 0.22  | 0.70  |
| Marmur and Mamane (2003)        | CALINE4              | NOx                 | Hourly        | N/A  | 0.34 | 0.04  | 0.75  |
|                                 | HIWAY2 <sup>5</sup>  | NOx                 | Hourly        | N/A  | 0.43 | 0.02  | 0.68  |
| Ganguly and Broderick (2009)    | GFLSM                | NOx                 | Hourly        | 0.76 | 0.50 | -0.16 | 0.85  |
| Kumar et al. (2006)             | AERMOD <sup>6</sup>  | SO2                 | Hourly        | N/A  | 1.06 | 0.08  | 0.72  |
|                                 | ISC2 <sup>7</sup>    | SO2                 | Hourly        | N/A  | 0.75 | -0.11 | 0.79  |

<sup>1</sup>: General Finite Length Source model;

<sup>2</sup>: Hybrid Method proposed by Ganguly and Broderick (2010).

<sup>3</sup>: Indian Institute of Technology Line Source model;

<sup>4</sup>: California Line Source Dispersion Model;

<sup>5</sup>: Highway Air Pollution Model;

<sup>6</sup>: Atmospheric Dispersion Modeling;

<sup>7</sup>: Industrial source complex dispersion model;



The scores of the statistical parameters for the results estimated based on the available traffic data sources are shown in Table 5-4. It can be found that the scores of the modeled results are consistent with findings of previous studies. The consistent scores indicate that the available data sources are able to help estimate roadside concentration with acceptable accuracy.

Specifically as shown by the FB scores, there exists slight underestimation in the PVR and ATR results and overestimation in micro-simulation results. When PVR data are supplemented by the operating mode distribution provided by the simulation data, the fractional bias becomes very negligible. The scores of IA and  $F_2$  for the ATR and PVR results are very similar and they are better than the scores of the micro-simulation results. The modeled results have the smallest error when the PVR data source are used with the operating mode distribution provided by the micro-simulation data.

**Table 5-4 Statistical parameters of modeled results**

| <b>Data Source</b> | <b>IA</b> | <b>NMSE</b> | <b>FB</b> | <b><math>F_2</math></b> |
|--------------------|-----------|-------------|-----------|-------------------------|
| ATR                | 0.49      | 0.84        | -0.11     | 0.70                    |
| PVR                | 0.46      | 0.79        | -0.16     | 0.62                    |
| PVR+OpMode         | 0.42      | 0.55        | 0.00      | 0.67                    |
| Micro-simulation   | 0.36      | 1.04        | 0.13      | 0.51                    |

The data analysis shows that the PVR data source is good for the project level  $PM_{2.5}$  analysis. It requires less effort to collect and provides the most accurate results among the available data sources. The normalized mean-square-error can be reduced by 30.5% if the PVR data are used with the operating mode distribution prepared based on the simulation data source. Though the ATR data source is readily available, it cannot provide enough information for the  $PM_{2.5}$  conformity analysis. In order to apply the ATR data source to estimate the emission factor, the PVR dataset must be supplemented to provide the traffic activity information.

## CHAPTER 6 : GIS-BASED SUPPORTING SYSTEM TAEHIA

The Traffic Air Emission and Health Impact Analysis (TAEHIA) System is aimed to facilitate the application of the three identified traffic data sources (i.e., ATR, PVR, and micro-simulation) into the PM<sub>2.5</sub> conformity analysis. TAEHIA is designed as a plug-in of the ArcGIS platform by using VB .NET language. The data conversions (i.e., converting the source data to inputs for MOVES; MOVES outputs to inputs for AERMOD; and AERMOD outputs to outcomes for PM<sub>2.5</sub> concentration analysis) are implemented automatically within the TAEHIA. In this project, the traffic air emission impact analysis functions have been developed. The TAEHIA system will be upgraded to include more functions in the future for health impact relevant analysis.

In this chapter, the architecture and basic functions of TAEHIA are introduced first. In Section 6.2, the TAEHIA's integrated method for conducting project-level PM<sub>2.5</sub> conformity analysis will be compared with the conventional method. The purpose of the comparison is to demonstrate the consistency of the TAEHIA method and the U.S. EPA's guideline on PM<sub>2.5</sub> conformity analysis and also show TAEHIA's capability of simplifying the conventional analysis process. In the Section 6.3, details of implementing the methodology developed in Chapter 4 into TAEHIA are described. In this section, the technical details of TAEHIA development are also presented.

### 6.1 Architecture and Basic Functions of TAEHIA

The architecture of TAEHIA is illustrated by Figure 6-1. There are three major modules in the TAEHIA framework. TAEHIA data processing functions are hosted in the TAEHIA database module. It is the key module of TAEHIA that provides data conversion, manipulation and storage services for the regional and project-level analysis modules. The two modules provide regional and project-level PM<sub>2.5</sub> conformity analysis functions. Since this project focus on the application of the available traffic data sources in the project-level analysis, the details of the project-level analysis module are described in this chapter. Information on regional module can be found in Appendix 1.

As shown by Figure 6-1, the architecture diagram of the TAEHIA system is designed to integrate U.S. EPA recommended emission analysis tool MOVES and dispersion analysis tool AERMOD in an integrated framework and GIS-based platform with an attempt to streamline the application of the two models with increased efficiency of analysis. In addition to well connecting the regional and project-level conformity analysis results in a single platform, such an integrated approach via the TAEHIA system can be beneficial to broader applications. For example, TAEHIA regional module can also be used for evaluating the environmental effects of land-use planning alternatives and identifying the PM<sub>2.5</sub> hot-spots. TAEHIA's project-level module can be used for analyzing the air quality impact of traffic control measures (TCM) and determining the population exposure level to the PM<sub>2.5</sub> pollutant for elementary students whose schools are located near major busy highway infrastructures.

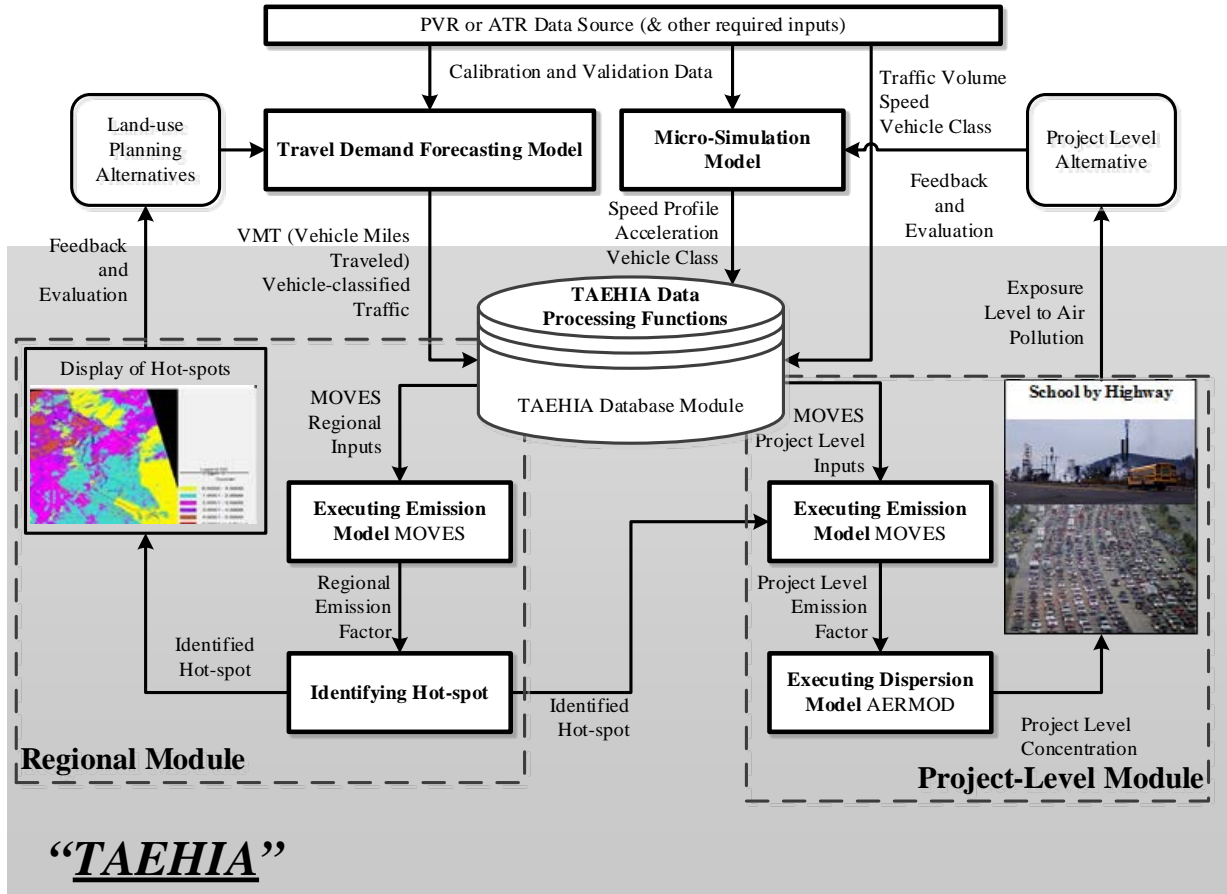


Figure 6-1 TAEHIA architecture

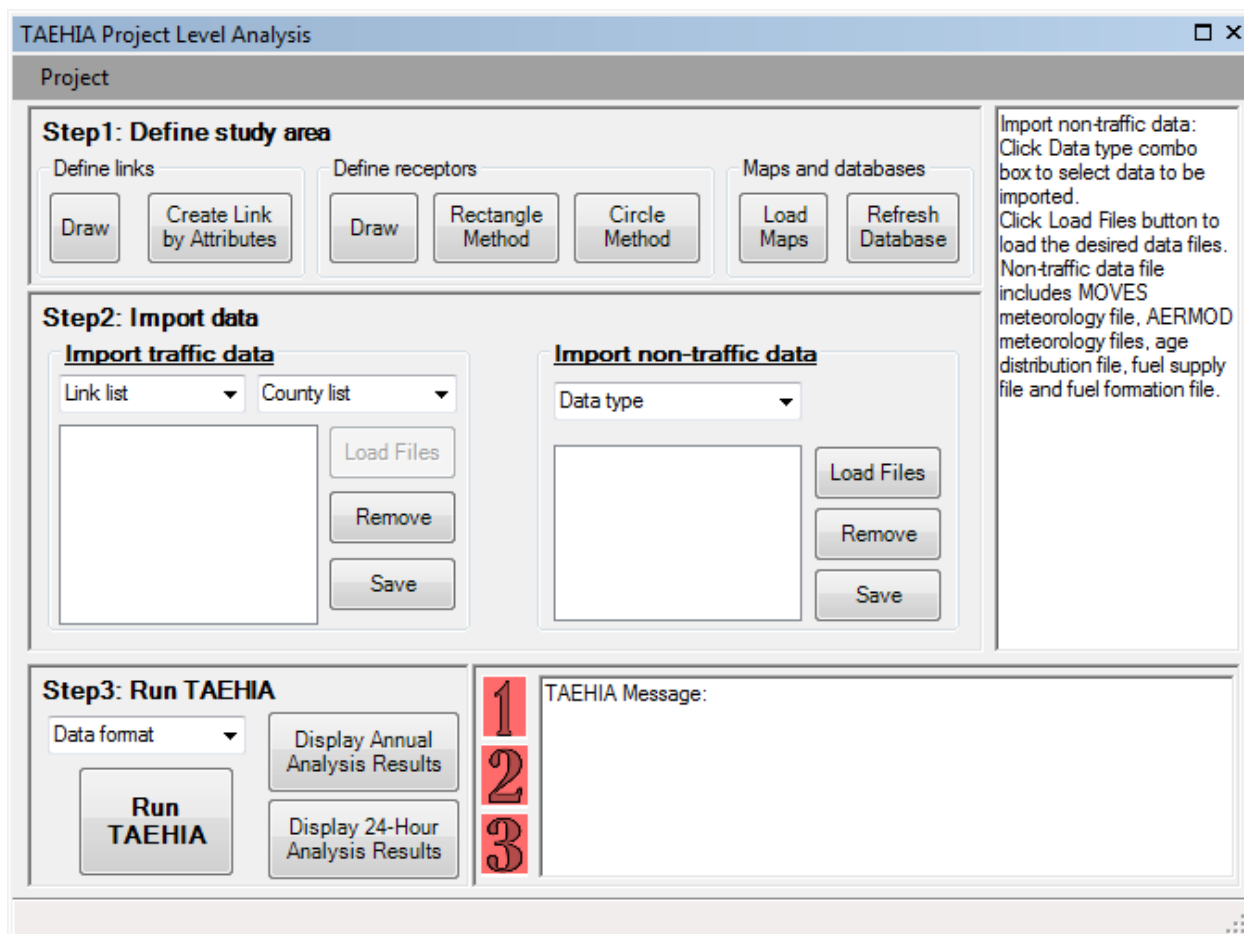


Figure 6-2 TAEHIA user interface

## 6.2 Conducting Project-Level PM<sub>2.5</sub> Conformity Analysis by Using TAEHIA

Steps of applying the TAEHIA for the project-level PM<sub>2.5</sub> conformity analysis are shown in Table 6-1. For the purpose of comparison, the steps of conventional method as described in the U.S. EPA guideline (U.S. EPA, 2010b) are also listed.

Comparing to the conventional analysis process, the improvement of the TAEHIA method is twofold. First, steps needed for the conformity analysis are greatly reduced by using TAEHIA. As shown by Table 6-1, there are twelve steps in the conventional method (U.S. EPA, 2014), but only six steps to be included in the TAEHIA method. In addition, the user's tasks involved in each step are largely simplified. In the conventional method, the user needs to prepare the input data in Excel files and text files, input the files into the MOVES and AERMOD tools, convert input/output between different tools and extract intermediate and final results from the database. In the TAEHIA method, user only needs to prepare the input data and import the data into database through the TAEHIA user interface. The TAEHIA will perform the data conversion for the user and prepare the output map automatically. The second improvement is that a graphic user interface is provided by the TAEHIA so that the user can define the geometry of the study links and receptors easily. Traditionally, the user needs to define links and receptors

in Excel or text files. It is not an easy task because neither the Excel or text file offers a spatial reference. Thus, the user needs to imagine the spatial features of the links and receptors and input their coordinates and geometry dimensions in the Excel or text file. In the TAEHIA method, the definition of links and receptors are performed in the ArcGIS through TAEHIA functions. The user is allowed to draw the analysis links and receptors according to the background map or satellite image of the study site. With the aid of TAEHIA functions, the definition of geometry features of the study site becomes much easier.

**Table 6-1 Steps of conducting project-level PM<sub>2.5</sub> conformity analysis**

| EPA Guideline (U.S. EPA, 2014)  | TAEHIA Method   | Comments   |
|---|---|--|
| <p><b>Step 1:</b> Preparing non-traffic input data for MOVES. The required datasets are age distribution, temperature and humidity, fuel supply and fuel formulation.</p> <p>Preparing non-traffic input data for AERMOD. The required datasets are surface meteorology profile and upper air meteorology profile for the study site.</p> | <p><b>Step 1:</b> Same as Step 1 of the EPAU.S. EPA method.</p>   | <p>N/A.</p>  |
| <p><b>Step 2:</b> Preparing traffic data from the available traffic data sources.</p>   | <p><b>Step 2:</b> Same as Step 2 of the EPAU.S. EPA method.</p>   | <p>N/A.</p>  |
| <p><b>Step 3:</b> Characterizing the road links into MOVES links.</p>   | <p><b>Step 3:</b> Loading background map of the study site. Characterizing the TAEHIA links and defining receptors via TAEHIA user interface.</p> | <p>Characterization of study links is performed in TAEHIA through a user-friendly graphic user interface. It is more straightforward than the conventional method.</p> |
| <p><b>Step 4:</b> Converting traffic data to MOVES input files (e.g., links, link source and operating mode distribution file).</p>   | <p><b>Step 4:</b> Input the traffic and non-traffic data into TAEHIA by using the TAEHIA user interface.</p>                                      | <p>Traffic data obtained from the available data sources are converted to the MOVES inputs automatically within the TAEHIA.</p>  |
| <p><b>Step 5:</b> Configuring MOVES RunSpec file and importing traffic and non-traffic inputs.</p>  | <p><b>Step 5:</b> Executing TAEHIA analysis.</p>  | <p>The MOVES analysis, AERMOD analysis and data conversion for MOVES outputs to AERMOD inputs are automatically performed by TAEHIA.</p>                               |
| <p><b>Step 6:</b> Executing MOVES analysis and extracting analysis results from the MOVES database.</p>   |   |  |
| <p><b>Step 7:</b> Post-processing the MOVES results and preparing emission factor inputs for AERMOD based on the MOVES results.</p>   |   |  |

**Table 6-1 Steps of conducting project-level PM<sub>2.5</sub> conformity analysis (cont'd)**

|   |  |   |
|---|--|---|
| <b>Step 8:</b> Characterizing the study road links into emission sources and defining the receptors for AERMOD.   |  |   |
| <b>Step 9:</b> Importing the information of the emission sources, emission factor of each source, receptors, and non-traffic data into the AERMOD input file. |  |   |
| <b>Step 10:</b> Executing AERMOD analysis and extracting annual and 24-hour analysis results from the AERMOD output files.                                    |  |   |
| <b>Step 11:</b> Post-processing the AERMOD results and determining the design values for the annual and 24-hour analysis.                                     |  |   |
| <b>Step 12:</b> Determining if the study area is conform to the NAAQS or not based on the design values.  | <b>Step 6:</b> Performing the conformity analysis based on the TAEHIA results. | The concentration map of the study area is prepared within the TAEHIA analysis. It becomes a user-friendly, straightforward way to analyze the conformity using the TAEHIA results. |

### 6.3 Applying Available Traffic Data Sources in PM<sub>2.5</sub> Conformity Analysis by Using TAEHIA

The process of applying the available traffic data sources in TAEHIA is illustrated by Figure 6-3. Each black box in the figure represents a TAEHIA function. Functions with check marks are already described in Chapter 4. Specifically, estimating emission factors based on the ATR and ATR datasets is described in Section 4.3; preparing MOVES traffic inputs based PVR and micro-simulation data is described in Section 4.4; and preparing MOVES traffic inputs based on micro-simulation data is described in Section 4.5. Details of remaining functions are described in subsections of Section 6.3. The number beside each box is the corresponding section ID.

Referring to Table 6-1, Step 1, Step 2 and Step 4 involved in the TAEHIA-based method are performed by the user. Technical details of Step 3 are discussed in Section 6.3.1. Details of Step 5 are described in Section 6.3.2, 6.3.3 and 6.3.4. Details of Step 6 are described in 6.3.5.

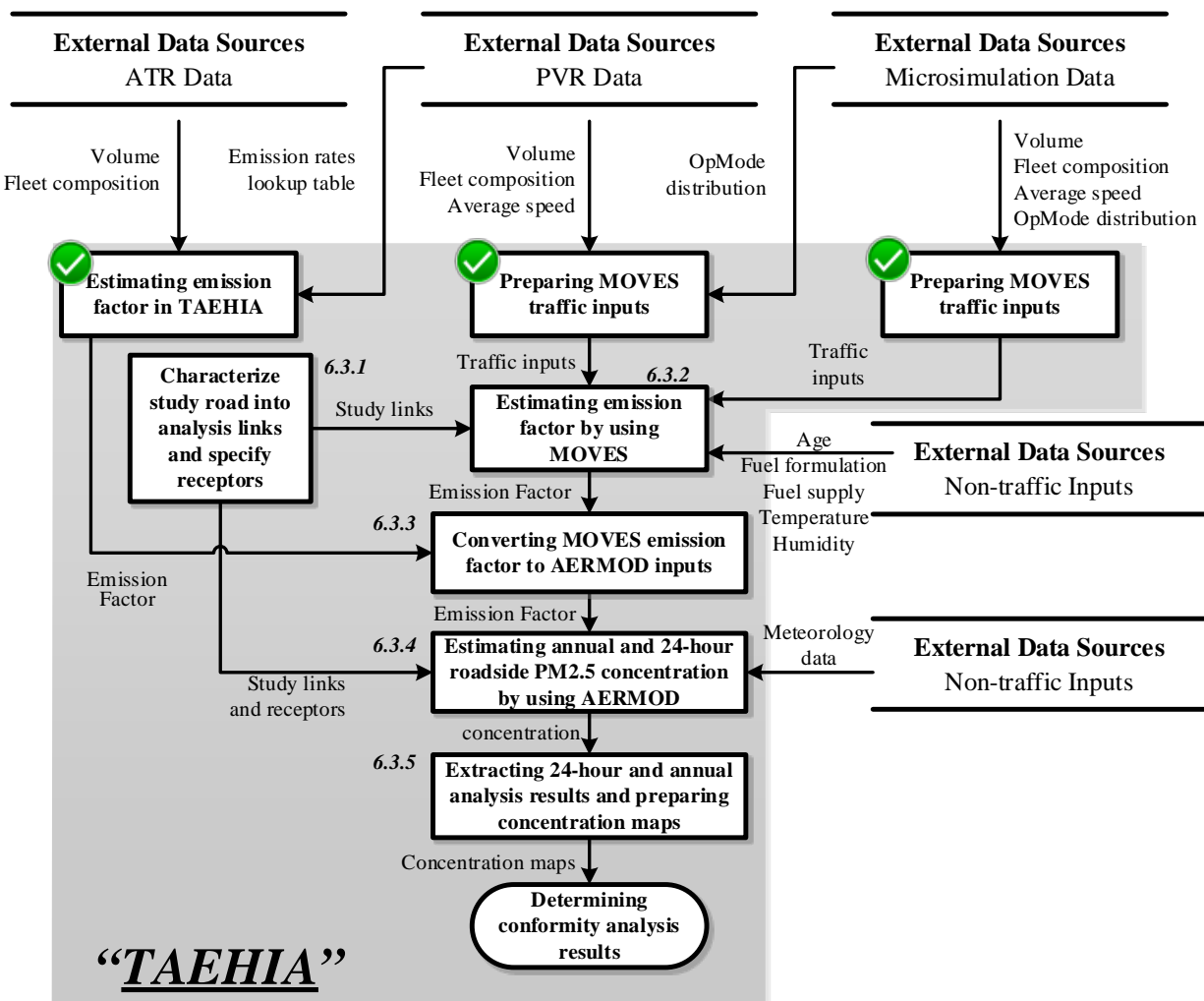


Figure 6-3 Applying available traffic data sources in TAEHIA

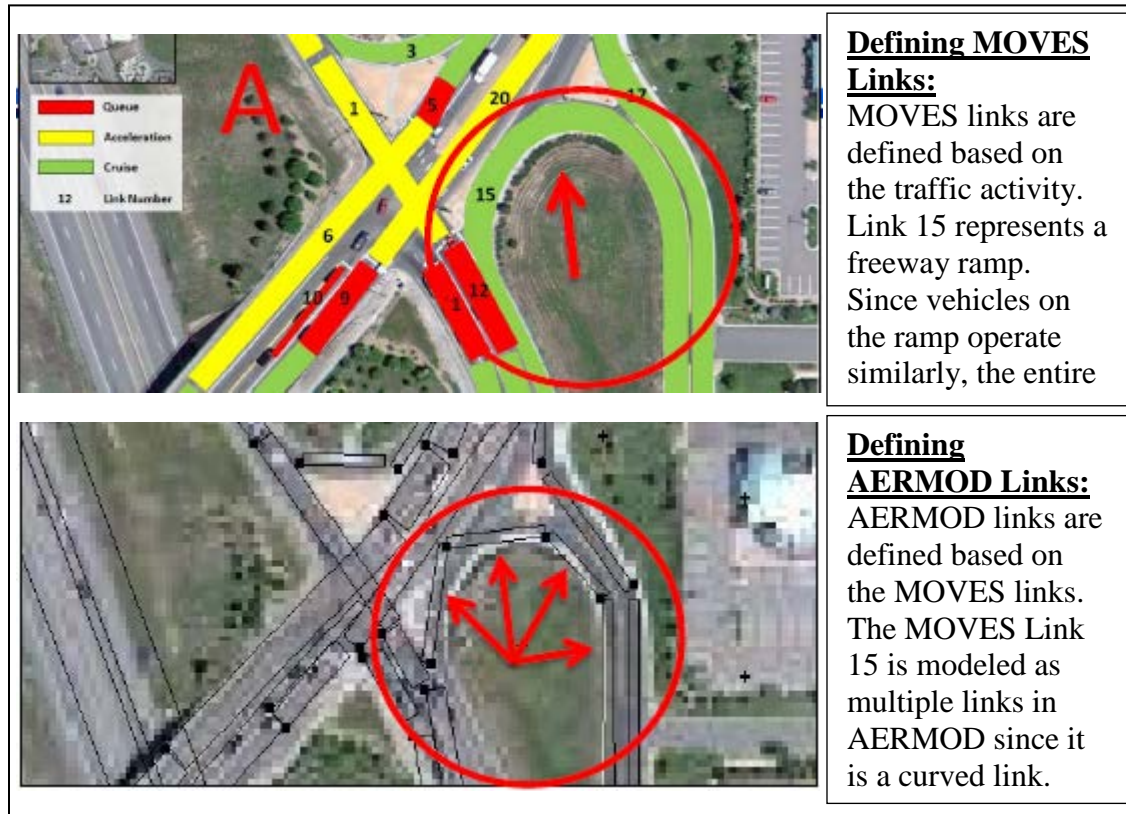
### 6.3.1 Characterization of Analysis Links and Receptors in TAEHIA

#### Characterizing Analysis Links

As shown by Figure 6-4, the MOVES and AERMOD links are configured separately in the conventional method described in the U.S. EPA guideline (U.S. EPA, 2010b). First, MOVES links are defined based on the traffic activity. Each MOVES link has similar average speed, link drive schedule or operating mode distribution. After MOVES analysis is completed, the AERMOD links (or emission sources) are defined on the basis of the MOVES links. Particularly, every MOVES link is at least one AERMOD emission source. If the MOVES link is a curved link, it will need to be modeled as more than one AERMOD emission sources.

In the conventional method, the AERMOD Links are actually a subset of MOVES links. If the user directly defines the AERMOD links and specifies the links of similar traffic activity, the MOVES links can be deduced accordingly. In this case, the user does not need to define the analysis links twice. Moreover, neither MOVES nor AERMOD provides a graphic user interface to define the analysis links. It is not straightforward but very time-consuming effort for users to

define the analysis links without a graphic aid tool. The two shortcomings of the conventional method are overcome in the TAEHIA system.



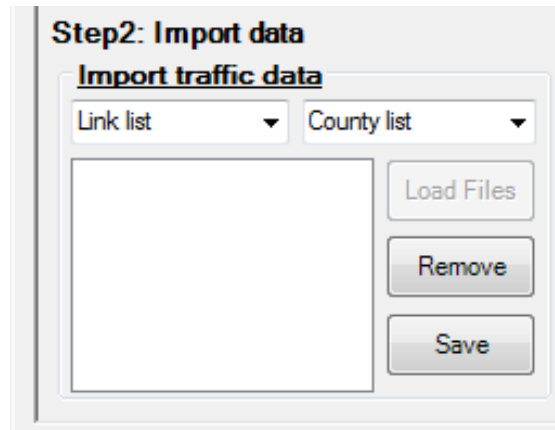
Note: Maps are obtained from U.S. EPA's PM hot-spot analysis training material (U.S. EPA, 2014)

**Figure 6-4 Process of characterizing analysis links in conventional method**

In the TAEHIA system, the user defines the analysis links by using the TAEHIA graphic user interface and the defined links are used by both MOVES and AERMOD model in the latter analysis. The links defined in TAEHIA should be rectangle areas so that they are consistent with the requirements of AERMOD links. As a consequence, the number of TAEHIA links is more than the number of MOVES links. If all TAEHIA links are used as the MOVES links, the time of running MOVES model in the TAEHIA analysis will be longer than the conventional method. In order to avoid the increasing of analysis time, the TAEHIA offers a function to group links.

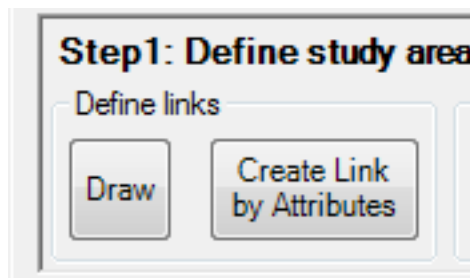
As shown by Figure 6-5, the function of grouping links is incorporated in the Import data panel. Firstly, links to be grouped are selected from the link list drop box. Then the traffic data of these links are imported by pressing the Load Files button. The grouped links will share the same traffic input. When the operation is done, the grouped links are simulated as a single link by the MOVES model.





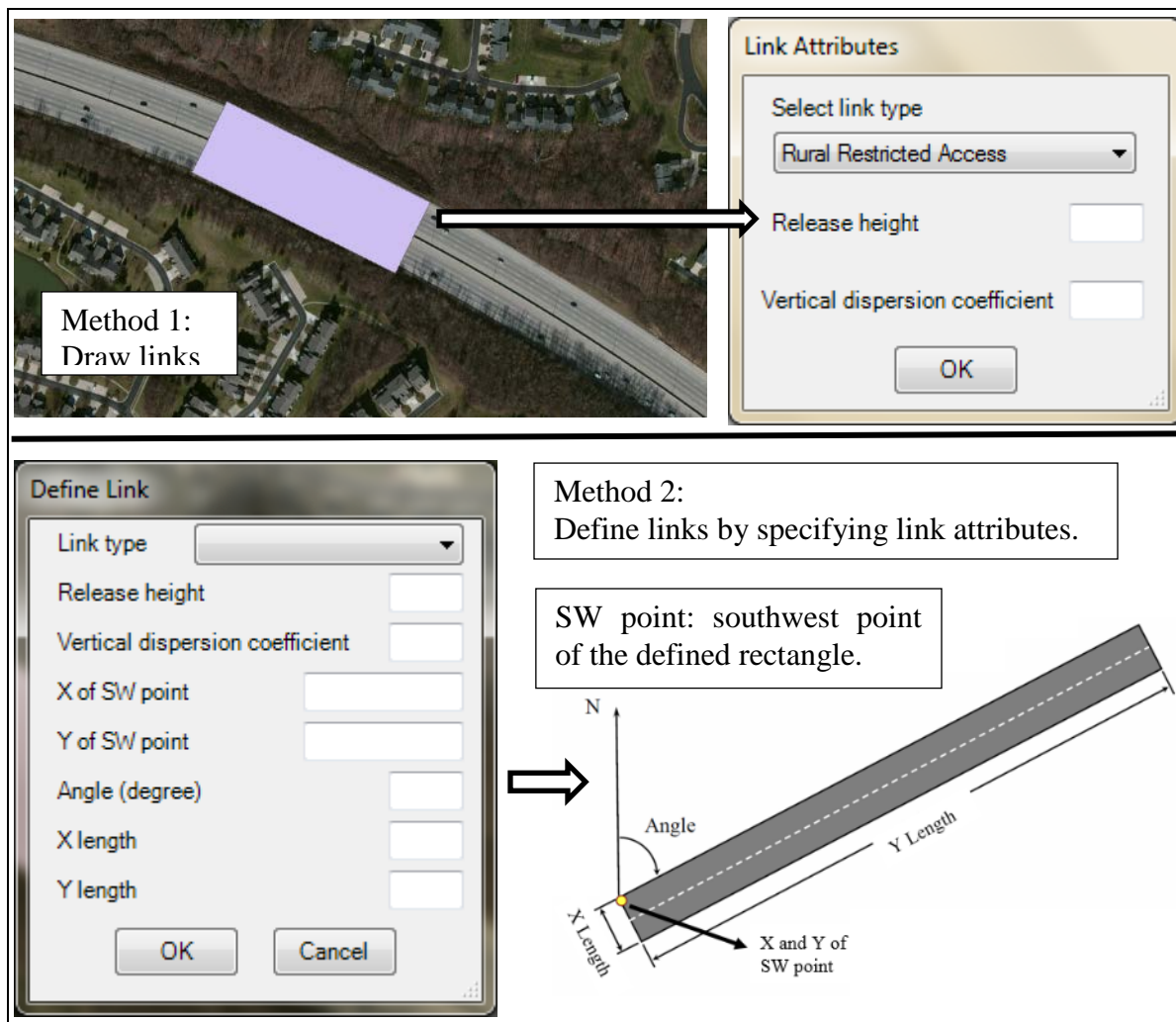
**Figure 6-5 Function of grouping TAEHIA links**

The TAEHIA offers two methods to define links. The two methods can be found at 'Define links' panel of the TAEHIA user interface (as shown by Figure 6-7). The user can draw links by referencing the highway configuration on the background map (as shown in the upper part of Figure 6-7). After finishing drawing, the user will be asked to provide additional information for the link, including link type, release height and vertical dispersion coefficient. Link type (i.e., rural restricted access, rural unrestricted access, urban restricted access, or urban unrestricted access) is used to define the class of the MOVES links. The remaining two parameters, i.e., release height and vertical dispersion coefficient, are dispersion parameters used by the AERMOD dispersion model.



**Figure 6-6 Functions of defining analysis links**

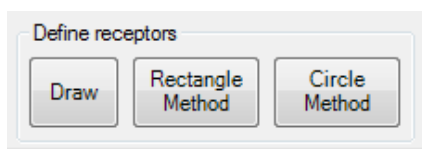
The TAEHIA links can also be created by specifying the link attributes (as shown in the lower part of Figure 6-7). There are eight attributes need to be specified by user. The first three attributes (i.e., link type, release height and vertical dispersion coefficient) are the same attributes specified in the previous method. The remaining attributes are defined in lower right corner of Figure 6-7.



**Figure 6-7 Defining links in TAEHIA**

Characterizing Receptors

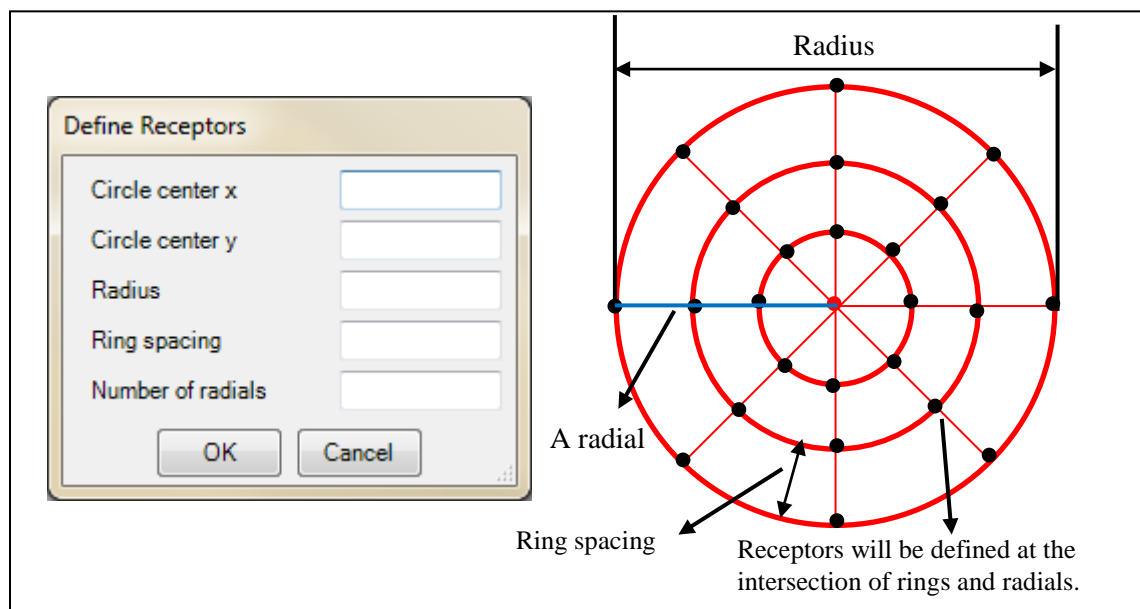
In the dispersion analysis, the user is required to specify the receptors. The pollutant concentration will be estimated at the receptors by using the dispersion model. In the conventional method, the receptors are defined by specifying the x and y coordinates for each receptor in the AERMOD input file. To achieve this, the user needs to measure the coordinates of the receptors in a GIS tool and put the measured coordinates in a text file in accordance with the AERMOD input file format. To simplify the process of defining the receptors, the TAEHIA offers three improved methods as described below. The functions of defining receptors can be found at the 'Define receptors' panel of the TAEHIA user interface (as shown by Figure 6-8).



**Figure 6-8 Functions of defining receptors**

First, the user can simply draw receptors at desired locations. When the Draw button is clicked, an edit session will be activated in the ArcGIS main window. The user can use the edit session to create points at the desired locations. When the user stops the edit session, the points added by the user will be converted to the receptors by the TAEHIA. Alternatively, the user can define receptors by using 'Rectangle Method' or 'Circle Method'. When the Rectangle Method button is pressed, the receptors will be generated in a rectangle with user specified spacing. Seven attributes are needed to define the rectangle (as shown by Figure 6-9). Specifically, X and Y of SW point represent the x and y coordinates for the southwest corner of the rectangle. The angle, x length and y length are similar as the corresponding features of the TAEHIA links. The definition of the three attributes can be found at the lower right corner of Figure 6-9. X spacing and Y spacing regulate the space between every two receptors along x and y axis. When Circle Method is selected, the receptors will be scattered within a circle. The circle is specified by the x and y coordinates of its center and the radius (as shown by Figure 6-10). The ring spacing and number of radials are defined in Figure 6-10.

**Figure 6-9 Defining receptors by using the Rectangle Method**



**Figure 6-10 Defining receptors in TAEHIA**

### 6.3.2 Preparation of MOVES Input Database and Execution of MOVES in TAEHIA

#### Preparation of MOVES Input Database

The MOVES input data is stored in a MySQL database. In order to perform a MOVES analysis, the tables of the MySQL database must be populated based on the user inputs, as shown by Table 6-2. The table names and fields of each table are illustrated in Table 6-2.

**Table 6-2 Tables and fields of MOVES input database**

| Table Name                     | Fields                 | Data Source                                  |
|--------------------------------|------------------------|--|
| link                           | linkID                 | specified by user in TAEHIA UI               |
|                                | countyID               | specified by user in TAEHIA UI               |
|                                | zoneID                 | MOVES database                               |
|                                | roadTypeID             | specified by user in TAEHIA UI               |
|                                | linkLength             | Calculated by TAEHIA based on geometry input |
|                                | linkVolume             | PVR or micro-simulation data source          |
|                                | linkAvgSpeed           | PVR or micro-simulation data source          |
|                                | linkDescription        | NA   |
| linksource-<br>typehour        | linkID                 | specified by user in TAEHIA UI               |
|                                | sourceTypeID           | MOVES database                               |
|                                | sourceTypeHourFraction | PVR or micro-simulation data source          |
| opmode-<br>distribution        | sourceTypeID           | MOVES database                               |
|                                | hourDayID              | PVR or micro-simulation data source          |
|                                | linkID                 | specified by user in TAEHIA UI               |
|                                | polProcessID           | MOVES database                               |
|                                | opModeID               | MOVES database                               |
|                                | opModeFraction         | Calculated by TAEHIA based on traffic input  |
|                                | opModeFractionCV       | null   |
| County                         | countyID               | specified by user in TAEHIA UI               |
|                                | stateID                | specified by user in TAEHIA UI               |
|                                | CountyName             | specified by user in TAEHIA UI               |
|                                | altitude               | MOVES database                               |
|                                | GPAFract               | MOVES database                               |
|                                | barometricPressure     | MOVES database                               |
|                                | barometricPressureCV   | null   |
| sourcetypeage-<br>distribution | sourceTypeID           | MOVES database                               |
|                                | yearID                 | PVR or micro-simulation data source          |
|                                | ageID                  | MOVES database                               |
|                                | ageFraction            | non-traffic input                            |

**Table 6-2 Tables and fields of MOVES input database (cont'd)**

| Table Name         | Fields   | Data Source                                 |
|--------------------|--|---|
| state              | stateID  | 39  |
|                    | stateName  | Ohio  |
|                    | stateAbbr  | OH  |
| year               | yearID   | PVR or micro-simulation data source         |
|                    | isBaseYear   | Calculated by TAEHIA based on traffic input |
|                    | fuelYearID   | PVR or micro-simulation data source         |
| zone               | zoneID   | MOVES database                              |
|                    | countyID   | specified by user in TAEHIA UI              |
|                    | startAllocFactor   | 1   |
|                    | idleAllocFactor  | 1   |
|                    | SHPAllocFactor   | 1   |
| zone-monthhour     | monthID  | PVR or micro-simulation data source         |
|                    | zoneID   | MOVES database                              |
|                    | hourID   | PVR or micro-simulation data source         |
|                    | temperature  | non-traffic input                           |
|                    | temperatureCV  | null  |
|                    | relHumidity  | non-traffic input                           |
|                    | heatIndex  | null  |
|                    | specificHumidity   | null  |
| relativeHumidityCV | null   |   |
| zoneroadtype       | zoneID   | MOVES database                              |
|                    | roadTypeID   | specified by user in TAEHIA UI              |
|                    | SHOAllocFactor   | 1   |
| fuel-formulation   | fuelFormulationID, fuelSubtypeID, RVP, sulfurLevel, ETOHVolume, MTBEVolume, TAMEVolume, aromaticContent, olefinContent, benzeneContent, e200, 2300, volToWtPercentOxy, BioDieselEsterVolume, CetaneIndex, PAHContent, T50, T90 | non-traffic input                           |
| fuelsupply         | countyID, fuelYearID, monthGroupID, fuelFormulationID, marketShare, marketShareCV  | non-traffic input                           |

The TAEHIA connects to the MySQL interface and then uses the SQL language to add, delete or modify the MOVES input tables. The MySQL commands that are used by TAEHIA to prepare the MOVES input database are shown by 6-3.

**Table 6-3 MySQL commands used for preparing MOVES input database**

|   |
|---|
| <p>To create a MOVES database:</p> <pre>Dim cmdTxt as String = "CREATE DATABASE databaseName" MySQLCommand.CommandText = cmdTxt MySQLCommand.ExecuteNonQuery()</pre>  |
| <p>To create a data table:</p> <pre>Dim cmdTxt as String = "CREATE TABLE tableName (     filedName1 filedDefinition     filedName2 filedDefinition     ...     ...)" MySQLCommand.CommandText = cmdTxt MySQLCommand.ExecuteNonQuery()</pre>   |
| <p>To populate a data table, the add value method of the MySQLCommand class is implemented in the TAEHIA database module. The syntax is:</p> <pre>Dim sqlLink As String = "insert into link (field_1, field_2, ..., field_n) values (@fieldValue_1, @fieldValue_2, ..., @fieldValue_n)" MySQLCommand.CommandText = sqlLink MySQLCommand.Parameters.AddWithValue("@fieldValue_1", actualValue1) MySQLCommand.Parameters.AddWithValue("@fieldValue_2", actualValue2) ... MySQLCommand.Parameters.AddWithValue("@fieldValue_n", actualValuen) MySQLCommand.ExecuteNonQuery()</pre> |

### Execution of MOVES

The MOVES analysis is executed based on the information stored in the RunSpec file. A RunSpec file records information such as the state and county of the analysis location, analysis time period, types of pollutants to be estimated and the names of input and output databases. Typically after the user sets up all required parameters listed in the navigation panel of the MOVES user interface, the RunSpec file will be generated by the MOVES software accordingly.

The RunSpec file is written in XML format. The XML file is easy to be accessed, created, edited or deleted by TAEHIA through the .NET framework. In fact, a RunSpec template is stored in the TAEHIA resource library. At each time all required datasets have been input into the TAEHIA database, the RunSpec template will be extracted from the library and then modified based on the inputs. After the modification is done, a new RunSpec file will be generated and then used for the MOVES analysis. Only a part of the RunSpec template needs to be modified each time. The sections in the RunSpec template that are changed in different TAEHIA analysis are listed in Table 6-4. The three asterisks (i.e., \*\*\*) marks the parameters that are specified by TAEHIA based on the inputs.

Once MOVES input database is populated and the RunSpec file is specified, the MOVES model is ready to be executed. Since MOVES is a java-based software, the command to execute MOVES is as follows:

```
java gov.epa.otaq.moves.master.commandline.MOVESCommandLine -r RunSpecPath
```

where, RunSpecPath is the file path of the RunSpec file prepared by TAEHIA.

**Table 6-4 The modified sections of the RunSpec template**

```

...
<geographicselections>
  <geographicselection      type="COUNTY"      key="****"
    description="****"/>
</geographicselections>
<timespan>
  <year key="****"/>
  <month id="****"/>
  <day id="****"/>
  <beginhour id="****"/>
  <endhour id="****"/>
  <aggregateBy key="Hour"/>
</timespan>
<roadtypes>
  <roadtype roadtypeid="****" roadtypename="****"/>
</roadtypes>
...

```

### 6.3.3 Conversion for MOVES outputs to AERMOD Inputs in TAEHIA

After the MOVES analysis is completed, TAEHIA extracts emission quantity from MOVES output database. The MySQL command for selecting the estimated emission quantity is:

```
SELECT linkID, emissionQuant FROM movesoutput where pollutantID = 110 order by linkID
```

After executing the command, link ID and the quantity of emitted PM<sub>2.5</sub> are obtained from the database. The emission quantity represents the overall mass of PM<sub>2.5</sub> that is emitted by vehicles in each MOVES link in an hour. Since the links used in the MOVES analysis may contain multiple TAEHIA links, the extracted emission quantity of each MOVES link needs to be post-processed so that the resulting emission rates can be used by individual TAEHIA links. To this end, the emission quantity of a MOVES link is divided by the number of vehicles observed in the MOVES link, the length of the MOVES link and the time of the analysis (3600 seconds). The resulting emission rate is in gram per vehicle per mile per second. Then the emission rate is applied to each TAEHIA link that is grouped in the MOVES link.

Once the emission rate of each TAEHIA link is obtained, the emission factor for AERMOD analysis can be calculated. The AERMOD model requires that the emission factor in gram per second per square meter is specified for each TAEHIA link. In order to calculate the emission factor, the emission rate of each TAEHIA link is multiplied by the number of vehicles observed in the link and the length of link. The resulting rate represents the overall emission quantity emitted by the TAEHIA link in a second. Then the rate is divided by the area of the link to get the emission factor required by AERMOD. Finally the estimated emission factor will be specified in the source pathway of the AERMOD input file. The preparation of AERMOD input file will be described in Section 6.3.4.

#### 6.3.4 Preparation of AERMOD Input File and Execution of AERMOD in TAEHIA

The AERMOD input file is prepared based on the geometry and dispersion attributes of each TAEHIA link, the emission factor of each TAEHIA link, the location of individual receptors, and the meteorology data of the study site. The geometry and dispersion attributes of a TAEHIA link is configured by using the method described in Section 6.3.1. Definition of receptors is also introduced in Section 6.3.1. The emission factor of each TAEHIA link is calculated based on method discussed in Section 6.3.3. The meteorology data is specified by user through the TAEHIA user interface.

The format of an AERMOD input file is shown in Table 6-5. The input file contains five pathways: control pathway (CO), source pathway (SO), receptor pathway (RE), meteorology pathway (ME) and output pathway (OU). The control pathway and output pathway are always the same in every TAEHIA analysis. In the control pathway, it is specified that the AERMOD analysis is performed for estimating 24-hour and annual PM<sub>2.5</sub> concentration. The height of each receptor is set as 1.8 meters. In the output pathway, the files that store the 24-hour and annual analysis result are defined. TAEHIA will look for concentration analysis results from the files when AERMOD analysis is completed.

In Table 6-5, the bold italic parameters are to be determined via the TAEHIA before running the AERMOD analysis. In the source pathway, the information of each TAEHIA link is extracted and the information is used to configure the parameters after the LOCATION and SRCPARAM key words. Specifically, SrcID represents the ID of the TAEHIA link; EF is the emission factor of the link; RelHgt is the release height; xint is the x length, yint is the y length and Szint is the vertical dispersion coefficient. The x and y coordinates of each receptor is specified in the receptor pathway after the DISCCART keyword. The surface and upper air profile files are specified in the meteorology pathway after SURFFILE and PROFFILE key words respectively.

The AERMOD executable file is stored in the TAEHIA resource library. After the AERMOD input file is prepared, the executable file is called and the AERMOD analysis is performed. The AERMOD results are stored in the files as designated in the output pathway.

**Table 6-5 Contents of an AERMOD input file**

|  |
|--|
| CO STARTING  |
| CO TITLEONE TAEHIA AEEMOND Run                           |
| CO MODELOPT FLAT CONC                                    |
| CO RUNORNOT RUN  |
| CO AVERTIME 24 ANNUAL                                    |
| CO FLAGPOLE 1.8  |
| CO POLLUTID PM2.5  |
| CO FINISHED  |
| SO STARTING  |
| SO ELEVUNIT METERS                                       |
| SO LOCATION <b>SrcID</b> AREA <i>x y</i>                 |
| SO SRCPARAM <b>SrcID EF RelHgt xint yint angle Szint</b> |
| ...  |
| SO SRCGROUP ALL  |
| SO FINISHED  |
| RE STARTING  |



```

RE ELEVUNIT METERS
RE DISCCART x y
...
RE FINISHED

ME STARTING
ME SURFFILE surfaceProfile
ME PROFFILE upperAirProfile
ME SURFDATA metStationID year
ME UAIRDATA metStationID year
ME PROFBASE 0
ME FINISHED

OU STARTING
OU POSTFILE 24 ALL PLOT ALL_24hr.pst
OU POSTFILE ANNUAL ALL PLOT ALL_ANNUAL.pst
OU FINISHED

```

### 6.3.5 Extraction of AERMOD Outputs and Generation of Concentration Map in TAEHIA

The TAEHIA extracts the concentration results from the AERMOD outputs that are stored in .pst files. A sample .pst file is shown in Table 6-6. Some columns are omitted because they are irrelevant to the estimation of the concentration of each receptor. In the table, the X and Y columns record the x and y coordinates of each receptor. AvgConc column is the average concentration in microgram per cubic meter for each receptor.

The 24-hour or annual concentration of a receptor is calculated in TAEHIA by considering all result points of the receptor. The number of concentration records for a receptor is determined based on the time span of the meteorology data. If the input meteorology data covers  $n$  years, there will be  $365*n$  data points for a receptor in the 24-hour analysis results and  $n$  data points in the annual analysis results. The 24-hour concentration of a receptor is the ninety-eight percentile concentration of the  $365*n$  data points in the 24-hour output file. The annual concentration of a receptor is the average concentration of the  $n$  data points in the annual output file.

**Table 6-6 Sample AERMOD outputs**

| <b>X</b> | <b>Y</b> | <b>Avg Conc</b> | <b>...</b> |
|----------|----------|-----------------|------------|
| 1429444  | 473755   | 0.00009         | ...        |
| 1429444  | 473955   | 0.01265         | ...        |
| 1429444  | 474155   | 0.06737         | ...        |
| 1429444  | 474355   | 0.00002         | ...        |

After the 24-hour and annual concentration of each receptor is estimated, the TAEHIA can output the 24-hour and annual concentration maps for the conformity analysis. To generate the amps, the concentration value of each receptor is first incorporated into the 24-hour and annual concentration maps. In order to estimate the concentration for areas among the receptors, the DSW interpolation method is automatically executed. The concentration of a location in the maps is determined by the concentrations of the closest receptors. Once the concentration of each point in the maps is obtained, the map is visualized according to the 24-hour and annual PM<sub>2.5</sub> NAAQS. For instance, the 24-hour PM<sub>2.5</sub> NAAQS is 35 microgram per cubic meter. If the

concentration of a point in the map is larger the 24-hour  $PM_{2.5}$  NAAQS, the color of the point is red. Otherwise, the color of the point is green. As a result, it is easy to identify if the project area conforms to the NAAQS or not. In addition, the spatial distribution of the non-conforming areas can also be identified from the map with ease.

## CHAPTER 7 : TAEHIA CASE STUDIES

The purpose of conducting TAEHIA case studies is three-fold: 1) to demonstrate major TAEHIA's functions in the project-level PM<sub>2.5</sub> conformity analysis; 2) to identify traffic operating parameters that can be used to supplement the current criteria for identifying PM<sub>2.5</sub> hot-spot analysis areas; and 3) to analyze the impact and effect of ramp metering (as one example of the traffic control measures) on the traffic source emission and dispersion level in the vicinity of the same case study site as mentioned in Chapter 5.

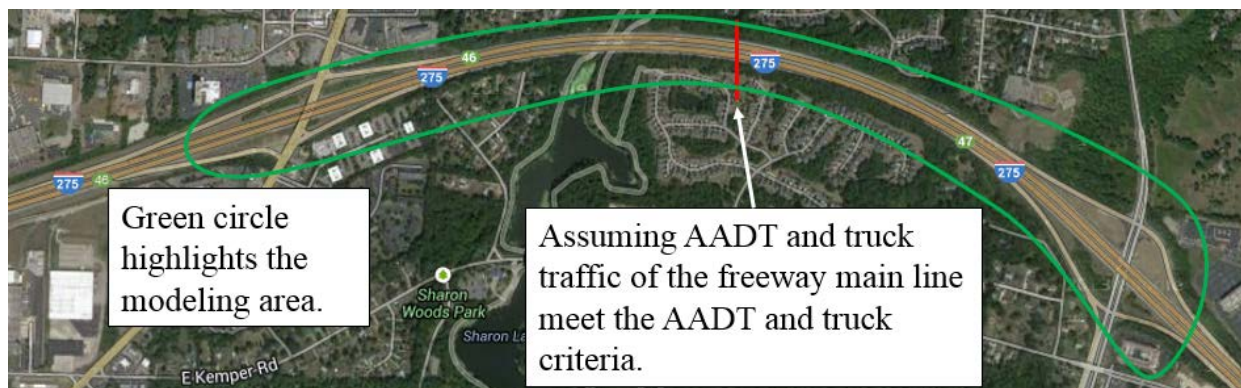
### 7.1 Case Study 1: Analyzing Criteria for Determining PM<sub>2.5</sub> Hot-Spot Analysis Areas

The object of case study 1 is to analyze traffic operating related criteria that require PM<sub>2.5</sub> hot-spot analysis. Currently, ODOT regulates that the PM<sub>2.5</sub> hot-spot analysis should be performed for a project area with 125,000 AADT and 10,000 truck traffic. If traffic conditions of a study site meet the criteria, the air quality of the site may or may not meet the NAAQS, since the temporal variation of traffic is not considered in the criteria even though it affects the roadside PM<sub>2.5</sub> concentration.

For example, if the daily traffic of a study site is assumed a little bit less than the current ODOT AADT criteria, and a large portion of the daily traffic is observed during the peak hours, the travel demand of that specific freeway may be greater than the capacity of the roadway, and the traffic flow may operate in a very congested condition during the peak hours. On the other hand, since the daily traffic is distributed during a day, the congested traffic status may not be reflected by the daily traffic measurement. It implies that even if daily traffic is the same, the percentage of congested traffic may vary largely and the peak traffic volumes may be different during the peak hours. It is well recognized that vehicle emissions vary with different traffic operation conditions, and congested traffic is supposed to incur much higher vehicle emissions than free traffic flow. Therefore, the total emissions may vary greatly even though the AADT is the same. This inspired our motivation to explore emission-oriented environmental impact of different hourly traffic distributions under a fixed daily traffic, i.e., with a fixed AADT condition.

The study site of the case study (shown as Figure 7-1) is a segment of I-275 in Cincinnati between exit 46 and 47. The PVR datasets have been collected at this site. In the case study, the study site is modeled in a micro-simulation model. The PVR data are used to calibrate the simulation model and provide traffic volumes of ramps and arterials. After the simulation run is completed, the simulation output data are compiled in TAEHIA to obtain the conformity analysis results.

In the simulation analysis, the daily traffic of the freeway mainline is assumed to be 125,000 and truck traffic is 10,000. In this case, the freeway traffic meets the current ODOT PM<sub>2.5</sub> hot-spot analysis criteria. Then the simulation model is applied to analyze simulation scenarios with different hourly traffic distributions. The simulation analysis aims to identify the scenario under which the air quality of the study site firstly meets the NAAQS. Then the traffic parameters of the scenario is analyzed and potential traffic parameters that can be used as the supplemental criteria for identifying the PM<sub>2.5</sub> analysis hot-spots will be found out.



**Figure 7-1 Study site of case study 1**

As the hourly distribution of traffic largely affects the roadside air quality when the daily traffic and truck volume are fixed at the current ODOT criteria, identifying the lower and upper boundaries of such an effect would be helpful to evaluate the current criteria. We assume that the least possible emission at the study site would occur if all traffic were equally distributed in each hour of a day, and the worst emission situation should happen if all traffic were clustered in peak hours. These two assumed cases are viewed as two extreme scenarios, and the magnitude of the current criteria could be identified through the study of the two cases. As a result, the current criteria may need adjustment. The current criteria need to be decreased if the traffic corresponding to the least emission scenario does not conform to the NAAQS; or the current criteria need to be increased if the emissions from traffic corresponding to the worst air quality still conform to the NAAQS.

More specifically, the two extreme scenarios designed to represent the best and worst air quality of the study site are scenario 1 and scenario 2 respectively. In scenario 1, all traffic is equally distributed in each hour of a study day (24 hours). In scenario 2, all traffic is distributed in the morning and afternoon peak hours. The morning peak hours (7:00 am - 9:00 am) and afternoon peak hours (16:00 pm - 19:00 pm) are identified by using the observed PVR data. Result of scenario 1 represents the minimum possible 24-hour and annual roadside  $PM_{2.5}$  concentrations and result of scenario 2 represents the maximum possible 24-hour and annual roadside  $PM_{2.5}$  concentrations.

The 24-hour concentration results of scenario 1 and scenario 2 are shown in Figure 7-2 and Figure 7-3, respectively. The annual results exhibit similar patterns and thus are not displayed here. In the figures, concentration in areas outside the black box is considered in the  $PM_{2.5}$  conformity analysis since area inside the black box is the area restricted from public access. The 24-hour  $PM_{2.5}$  NAAQS is  $35 \mu g/m^3$ . The green color as shown in Figure 7-2 and Figure 7-3 indicates that the underlying area conforms to the NAAQS and red color represents that the area does not conform to the NAAQS.

In scenario 1, traffic volume of each hour is much less than the capacity and thus no vehicle is observed in the congested traffic. As a result, the air quality of the study site conforms to the NAAQS. In scenario 2, all vehicles operate in the congested traffic. As shown by Figure 7-3, the air quality of the study site does not conform to the NAAQS. In particular as indicated by the red circles, the air quality close to the freeway weaving area is the worst situation.



Figure 7-2 Concentration map of scenario 1



Figure 7-3 Concentration map of scenario 2

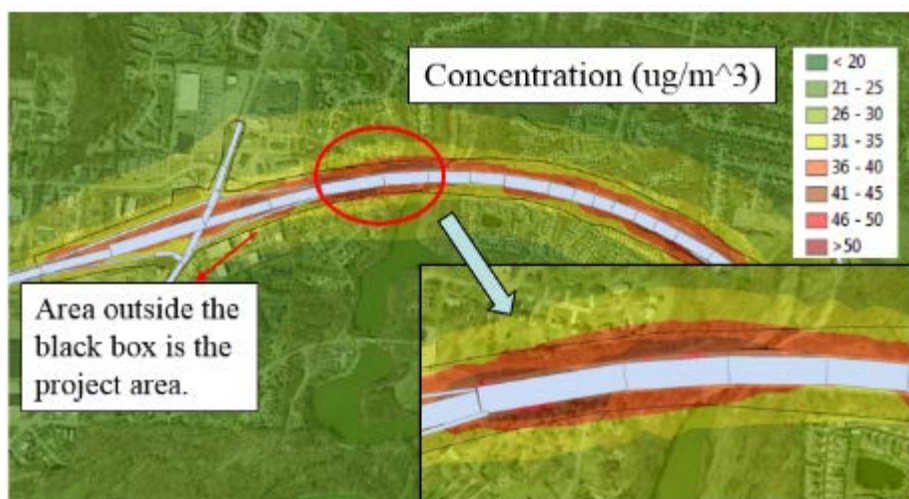
Since the air quality of scenario 1 conforms to the NAAQS and the air quality of scenario 2 does not, it indicates that the current AADT and truck traffic criteria are neither too high nor too low. Consequently, the next step aims to identify the threshold hourly traffic distribution of the current AADT and truck traffic under which the air quality of the study site firstly meets the NAAQS. In order to identify the threshold hourly distribution, the trial-and-error method is used to test different distribution scenarios and scenario 3 is tested next. Scenario 3 is designed so that all vehicles (115,000 cars and 10,000 trucks) are distributed in a day according to the empirical fractions observed on Ohio freeways. The hourly distribution is exhibited by Table 7-1.

Table 7-1 Hourly distribution of traffic for scenario 3

|            |      |      |      |      |      |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hour       | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
| Percentage | 0.8% | 0.5% | 0.4% | 0.4% | 0.8% | 2.2% | 5.5% | 8.1% | 6.7% | 5.0% | 4.5% | 4.7% |
| Hour       | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   |
| Percentage | 4.9% | 5.1% | 5.9% | 7.4% | 8.3% | 8.6% | 6.2% | 4.2% | 3.5% | 3.0% | 2.2% | 1.1% |



After the study site is simulated and the traffic data collected, the simulation data are input into the TAEHIA to get the concentration map of the study area. The non-traffic data are the same data used in Chapter 5 for evaluating the applicability of the available data sources. The concentration map of scenario 3 is illustrated by Figure 7-4. Compared with scenario 2, fewer vehicles are distributed in peak hours (7:00 am to 9:00 am, and 16:00 pm to 19:00 pm) and thus fewer vehicles are involved in the congested traffic flows. As a result, the non-conforming area of scenario 3 is much smaller than scenario 2. Result of scenario 3 indicates that reducing the percentage of vehicles distributed in peak hours can help improve the air quality of the study site. Thus, in next scenarios, the percentage of peak hour traffic is further reduced and the concentration maps of these scenarios are analyzed.



**Figure 7-4 Concentration map of scenario 3**

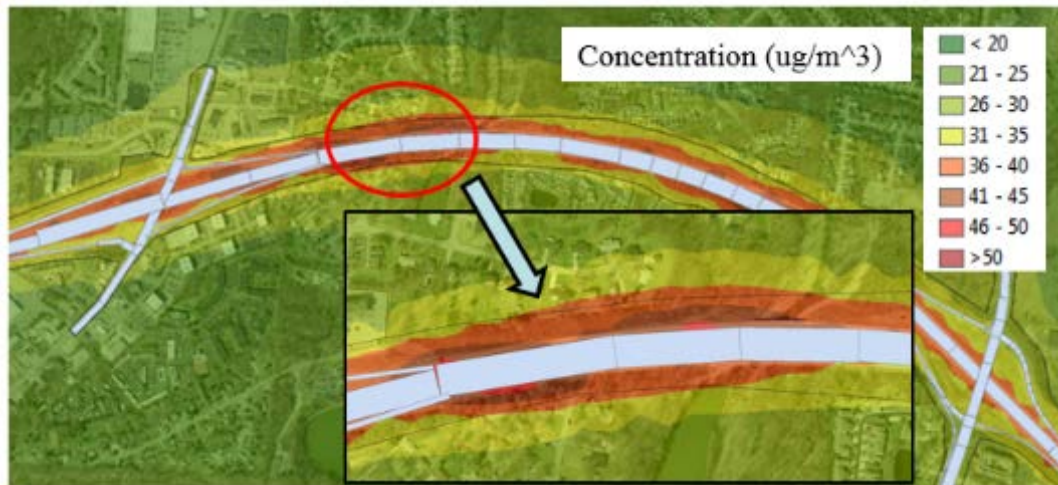
In scenario 4, the percentage of vehicles in a peak hour is reduced by 1% comparing to Scenario 3 and in total 7% of the daily traffic is reduced from the peak hours. The reduced vehicles are distributed in the non-peak hours according to the weight of traffic volume in the non-peak hours. For example, 0.8% of the daily traffic is observed in the first hour in scenario 3. In scenario 3, 44.6% of traffic is in peak hours and 55.4% of traffic in non-peak hours. The amount of traffic in the first hour accounts for about  $0.8\%/55.4\% = 1.4\%$  of the traffic volume observed in the non-peak hours. Therefore, 1.4% of the reduced traffic should be added to the first hour in scenario 4. As a result, there will be  $0.8\% + 7\% * 1.4\% = 0.9\%$  of the daily traffic in the first hour in scenario 4.

**Table 7-2 Hourly distribution of traffic for scenario 4**

|            |      |      |      |      |      |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hour       | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
| Percentage | 0.9% | 0.6% | 0.5% | 0.5% | 0.9% | 2.4% | 4.5% | 7.1% | 5.7% | 5.5% | 5.0% | 5.2% |
| Hour       | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   |
| Percentage | 5.4% | 5.7% | 6.5% | 6.4% | 7.3% | 7.6% | 6.9% | 4.6% | 3.9% | 3.3% | 2.4% | 1.2% |

The concentration map of scenario 4 is shown by Figure 7-5. The non-conforming area still exists close to the freeway weaving area. Nonetheless, the non-conforming area as shown in

Figure 7-5 becomes smaller than Figure 7-4. The results indicate that the air quality of the study site may be improved by further reducing the percentage of traffic in peak hours. Therefore in scenario 5, percentage of vehicles in a peak hour is reduced by 2% comparing to Scenario 3, and totally 12% of the total traffic is reduced from the peak hours. The reduced traffic is assigned to non-peak hours by using the same method used in scenario 4. The hourly traffic distribution is shown in Table 7-2.

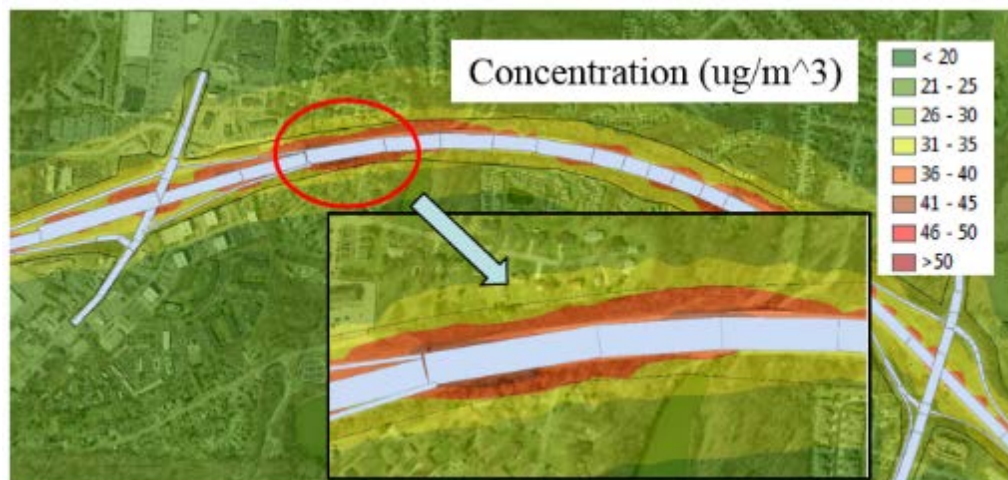


**Figure 7-5 Concentration map of scenario 4**

**Table 7-3 Hourly distribution of traffic for scenario 5**

|            |      |      |      |      |      |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hour       | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
| Percentage | 1.0% | 0.6% | 0.5% | 0.5% | 1.0% | 2.7% | 3.5% | 6.1% | 4.7% | 6.1% | 5.5% | 5.7% |
| Hour       | 13   | 14   | 15   | 16   | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   |
| Percentage | 6.0% | 6.2% | 7.2% | 5.4% | 6.3% | 6.6% | 7.5% | 5.1% | 4.3% | 3.6% | 2.7% | 1.4% |

The 24-hour concentration analysis results of scenario 5 are shown by Figure 7-6. It can be found that the red area just reaches the border to the black boundary line. Thus the air quality of the study site first conforms to the NAAQS. In the next step, traffic parameters of each scenario are analyzed. These traffic parameters may be used to supplement the current criteria for identifying the PM<sub>2.5</sub> hot-spots.



**Figure 7-6 Concentration map of case scenario 2**

In this case study, traffic operation of each scenario is represented by two traffic parameters: number of congested hours in a day and fraction of vehicles in congested traffic. The congested hour is identified by LOS. If the traffic with LOS E or F lasts more than 15 minutes in an hour, the hour is categorized as a congested hour. The fraction of vehicles in congested traffic is the percentage of vehicles observed in congested hours.

The score of the two parameters for the five scenarios are shown by Table 7-4. In addition to AADT and truck traffic, it is recommended that the two traffic parameters, i.e., number of congested hours and fraction of vehicles in congestion, be added to the current criteria to identify the PM<sub>2.5</sub> analysis hot-spots. Since scenario 5 represents the threshold condition, the threshold number of congested hours is 3 and the fraction of vehicles in congested traffic is 21%.

**Table 7-4 Traffic parameters of each scenario**

| Scenario | # of congested hours | Fraction of vehicles in congestion |
|----------|----------------------|------------------------------------|
| 1        | 0                    | 0.00                               |
| 2        | 15                   | 1.00                               |
| 3        | 8                    | 0.54                               |
| 4        | 8                    | 0.52                               |
| 5        | 3                    | 0.21                               |

## 7.2 Case Study 2: Analyzing Effects of Traffic Control Measures on Project Level PM<sub>2.5</sub> Emissions

The objective of case study 2 is designed to identify effects of the traffic control measures on the traffic operating related variables and further determine the impact of the traffic operating variables on project-level emission assessments. In this case study, traffic operating status of the study ramp and freeway segment is affected by the ramp meters on the on-ramp. Travel time and delays of the freeway and on-ramp are measured when the ramp meters are turned on and off. Then the delay data are linked to the concentration map of the study site. By analyzing the delay



and corresponding concentration, the effect of ramp meters on the traffic operating parameter and on air quality can be determined.

Study site of the case study is a segment of I-275 in Cincinnati, Ohio near exit 46 (as shown by Figure 7-7). The ramp meters are set at the eastbound on ramp of exit 46. Delays are measured for the specified segments of on-ramp and freeway. The segments are marked by the dark blue dashed line in Figure 7-7. Same as case study 1, the study site is analyzed in a simulation model. Data sources used for this case study include PVR and micro-simulation data sources. The PVR data are used to calibrate the simulation model and provide traffic volume of ramps and arterials. Simulation data are used in the TAEHIA to obtain the conformity analysis results.



**Figure 7-7 Study site of case study 2**

The daily traffic of the study site is set as 125,000 and the truck volume is 10,000 and the hourly traffic distribution of this case study is shown in Table 7-5. As identified by case study 1, the air quality of the study area will not conform to the NAAQS under the specified traffic condition. If the ramp meters can help reduce vehicle emissions, the air quality of the study site should become better when the ramp meters are turned on.

**Table 7-5 Hourly distribution of traffic for case study 2**

|            |      |      |      |      |       |       |      |       |      |      |      |      |
|------------|------|------|------|------|-------|-------|------|-------|------|------|------|------|
| Hour       | 1    | 2    | 3    | 4    | 5     | 6     | 7    | 8     | 9    | 10   | 11   | 12   |
| Percentage | 0.6% | 0.4% | 0.3% | 0.3% | 0.6%  | 1.7%  | 7.5% | 10.1% | 8.7% | 3.9% | 3.5% | 3.7% |
| Hour       | 13   | 14   | 15   | 16   | 17    | 18    | 19   | 20    | 21   | 22   | 23   | 24   |
| Percentage | 3.9% | 4.0% | 4.6% | 9.4% | 10.3% | 10.6% | 4.8% | 3.3%  | 2.7% | 2.4% | 1.7% | 0.9% |

In the simulation analysis, an analysis day is divided into three periods: congested hours, non-congested hours and overnight hours. A congested hour is identified by two conditions: the hour between 6:00 am to 22:00 pm and the LOS of the study freeway segment is E or F for more than 15 minutes in each of these hours. The hours between 6:00 am to 22:00 pm are non-congested hours if they do not meet the above two conditions. Overnight hours are hours between 22:00 pm to 6:00 am. The ramp meters are turned on only during non-congested hours

and congested hours, and not the overnight hours. The traffic volume during overnight hours is very small. The effect of the ramp metering is not significant and thus it is turned off during overnight hours.

In order to identify a suitable ramp metering plan, two ramp metering plans are tested during the congested and non-congested hours. The first ramp metering plan has 4 seconds cycle length with 2 seconds green and 2 seconds red. The second plan has 6 seconds cycle length with 2 seconds green and 4 seconds red. The average emission rate is used as the parameter to identify the performance of the ramp metering plans for different time periods. The analysis results are shown by Table 7-6.

**Table 7-6 Average emission rate (g/veh/mile) of freeway mainline and on-ramp**

|          |                         | Non-congested<br>Hours | Change% | Congested<br>Hours | Change% |
|----------|-------------------------|------------------------|---------|--------------------|---------|
| No RM    | Basic freeway segment   | 0.021                  | NA      | 0.057              | NA      |
|          | Freeway weaving segment | 0.030                  | NA      | 0.128              | NA      |
|          | On ramp                 | 0.021                  | NA      | 0.022              | NA      |
| 4-sec RM | Basic freeway segment   | 0.021                  | 0%      | 0.020              | -65%    |
|          | Freeway weaving segment | 0.029                  | -3%     | 0.066              | -48%    |
|          | On ramp                 | 0.230                  | +995%   | 0.183              | +732%   |
| 6-sec RM | Basic freeway segment   | 0.022                  | +5%     | 0.058              | -2%     |
|          | Freeway weaving segment | 0.027                  | -10%    | 0.126              | -2%     |
|          | On ramp                 | 0.214                  | +919%   | 0.227              | +932%   |

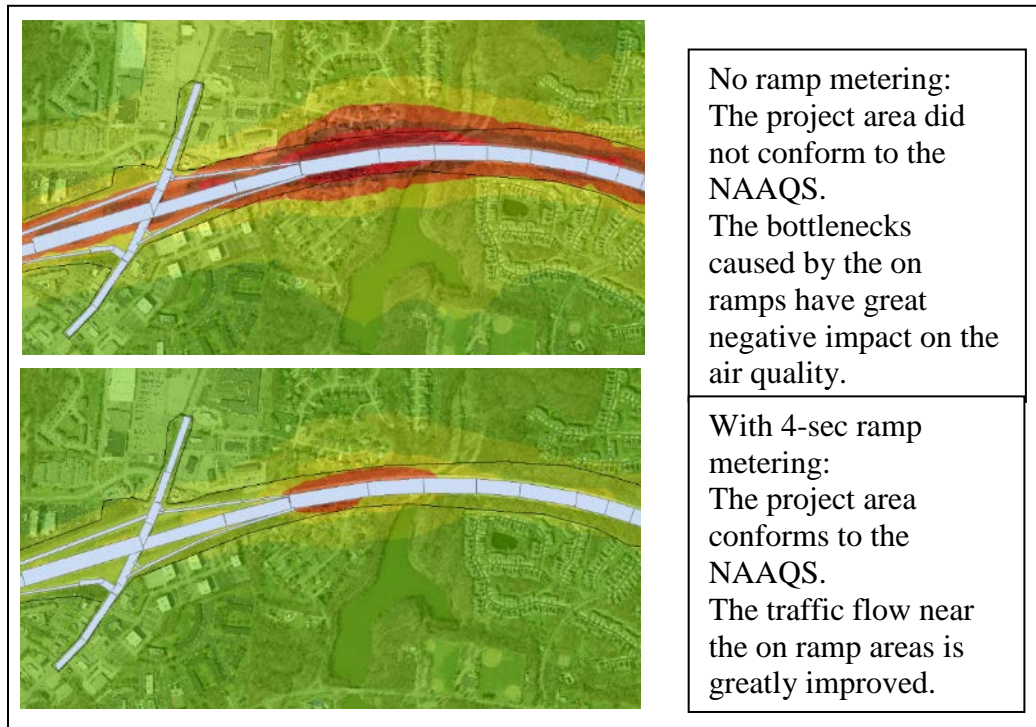
During non-congested hours, both ramp metering plans did not largely reduce the emission rates on basic freeway segment and freeway weaving segment but significantly increase the emission rate of the on ramp. During congested hours, the 4-second ramp meters significantly reduce the emission rate of the basic freeway segment and freeway weaving segment. On the other hand, the effects of 6-second ramp meters on freeway segments during congested hours are very small. The results indicate that the 4-second ramp meters outperform the 6-second ramp meters during congested hours. Therefore, the 4-second ramp metering is identified as a suitable ramp metering plan for this case study.

Next, the results of delay analysis of the freeway segment and on-ramp are estimated. The results are shown in Table 7-7. Although the average and total delay for the on-ramp are largely increased when the ramp meters are turned on, the total delay of the study area reduces significantly.

**Table 7-7 Delay (seconds) of on-ramp and freeway segment**

|                      | Avg. Freeway<br>Delay | Avg. Ramp<br>Delay | Total Freeway<br>Delay | Total Ramp<br>Delay | Total Delay |
|----------------------|-----------------------|--------------------|------------------------|---------------------|-------------|
| No RM                | 33.3                  | 5                  | 3113861                | 20171               | 3134033     |
| RM                   | 9.6                   | 319.2              | 897690                 | 1287728             | 2185418     |
| Total Reduced Delay: |                       | 948615             |                        | Reduced %:          | 30.3%       |

After the TAEHIA analysis, the resulting concentration map of case study 2 is shown by Figure 7-8. It can be identified from the maps that the ramp meters do bring positive environmental effect for the study site. The deduction of 30.3% total delay will lead to the significant decrease of the non-conforming area. The case study demonstrates the great potential of traffic control measures to reduce the vehicle emission on the mainline of a freeway.



**Figure 7-8 Concentration maps for case study 2**

## CHAPTER 8 : CONCLUSIONS AND RECOMMENTATIONS

### 8.1 Conclusions

#### *8.1.1 Conclusions to Applying Available Traffic Data Sources in PM<sub>2.5</sub> Conformity Analysis*

Three traffic data sources (i.e., the ATR, PVR and micro-simulation data sources) have been identified in Ohio to be applicable to the PM<sub>2.5</sub> conformity analysis. The ATR data source stores the aggregated traffic data collected by using automatic traffic recorders. It can also be obtained from short-term traffic count campaigns and travel demand forecasting analysis. The ATR data source usually contains hourly or 15-minute traffic volume and vehicle composition. Since the ATR source includes the aggregated traffic information only, the size of the data source is relatively small. Thus, the ATR data can be archived from the ODOT database and acquired from ODOT website. The PVR data source stores raw data collected by automatic traffic recorders and short-term traffic count campaigns. It provides individual vehicle's timestamp, class and speed information. Due to the large sized PVR datasets, it is not routinely archived from the ODOT database. ODOT is able to save the PVR data for a specified time period under request of users. The micro-simulation data source provides the most detailed traffic information, including individual vehicle's class, speed profile and acceleration profile. To obtain the micro-simulation data for a specific location or network, a simulation model must be set up specifically for the site in the simulation environment, and the built-up simulation model must pass the calibration and validation prior to its use for the project.

Since the MOVES model is required by U.S. EPA for estimating transportation emissions, the method for applying the identified traffic data sources in the MOVES model is emphasized in the research project. Findings about using the data sources in estimating emission factors are summarized as follows.

- The ATR data source is readily available in Ohio and it provides rich traffic flow rate and fleet composition data in 15-minute or 1-hour intervals. However, the aggregated traffic data are not detailed enough to be used as the traffic activity inputs to the MOVES. The study result suggests that the PVR data be used to provide the traffic activity data to supplement the ATR data source to meet the need of conducting the conformity analysis.
- The PVR data source is capable to provide the traffic inputs for running the MOVES model. However, the traffic activity data provided by the PVR data only contain average speed information. In order to improve the accuracy of the modeled emission factor, the operating mode distribution data prepared based on the micro-simulation data are recommended to be used along with the PVR data in estimating the emission factors.
- Calibration and validation of the simulation model must be passed prior to applying the simulation model to generate the traffic data. The PVR data source is recommended as the data source for the simulation model calibration and validation.
- The model accuracy of applying the three data sources in estimating emission factors has been evaluated by using the sample data collected at the case study site in Cincinnati, Ohio. The PVR data source is recognized good for the project level PM<sub>2.5</sub> analysis. It requires less data collecting effort while being capable of providing the most accurate results compared to other two data sources. Moreover, the normalized mean-square-error can be reduced by 30.5% if the PVR data are used with the operating mode distribution data that are generated from the micro-simulation data source.

### *8.1.2 Conclusions to Applying TAEHIA in PM<sub>2.5</sub> Conformity Analysis*

The methodology for applying the available data sources for the PM<sub>2.5</sub> conformity analysis has been tested with the TAEHIA tool via case studies. The TAEHIA is developed as an ArcGIS plug-in by using the VB .NET language. It provides a user-friendly graphic user interface to simplify the process of the project-level PM<sub>2.5</sub> conformity analysis. Comparing to the conventional analysis steps recommended by U.S. EPA, the improvement brought by the TAEHIA method reflects in two perspectives. First, the steps needed for the conformity analysis are greatly reduced by using the TAEHIA. There are twelve steps in the conventional method, but only six steps to be needed with the TAEHIA method. In addition, the user's tasks involved in each step are simplified. Second, the user can define the geometry of the project links and receptors easily through a user-friendly graphic interface embedded within the TAEHIA. Traditionally, the user needs to define links and receptors in Excel or text files. It is an uneasy task since neither the Excel or text file offers a spatial reference. As a consequence, the user needs to depict the spatial features of the links and receptors and input their coordinates and geometry dimensions in the Excel or text file. In the TAEHIA method, the definition of links and receptors are performed in the ArcGIS through specifically designated functions embedded within the TAEHIA. The user is allowed to draw the analysis links and receptors according to the background map or satellite image of the study site. With the aid of those TAEHIA functions, the definition of geometry features of the study site becomes much easier for users.

As shown by the case studies, the TAEHIA-based system makes it much simpler to determine the conformity of a project area by using the concentration maps output. Additionally, the TAEHIA can be used for other air quality related analysis, such as determining the effects of traffic flow parameters and traffic control measures on PM<sub>2.5</sub> concentrations; and studying the criteria for determining the hot-spot analysis areas. Moreover, the current prototype provides a solid foundation to be expanded with more functions in the future; for example, health impact analysis, incorporating more data sources, and so forth.

## **8.2 Implementation Plan**

Major products from the research are the integrated methodology of applying the available traffic data sources in the project-level PM<sub>2.5</sub> conformity analysis and the GIS-based support tool, i.e., TAEHIA that is used to make an easy implementation of the proposed methodology. There is a great potential that the developed methodology and associated tool could contribute greatly to the development of a state-wide guideline for conducting the project-level PM<sub>2.5</sub> conformity analysis. Nine recommendations are suggested to be considered as the implementation plan will be developed in details. These nine recommendations are described as follows.

### *8.2.1 Recommendations for Implementation*

It is recommended that the TAEHIA tool is applied for the quantitative hot-spot conformity analyses in PM<sub>2.5</sub> nonattainment and maintenance areas. In current U.S. EPA guideline, there is no recommended tool for streamlining the data preparation, data conversion and results post-processing involved in the conformity analyses. In many practices, these tasks are carried out manually. With the use of the TAEHIA, these tasks can be completed in an automated process as directed by TAEHIA. It expects to save the user's time and efforts in required data manipulation, compared to the conventional approach.

### *8.2.2 Key Initial Step to Implement Proposed Methodology and Associated Tool*

The key step required to implement TAEHIA is a continuation of discussions between the research team and the technical liaisons. TAEHIA training courses should be given to the technical liaisons before they use the tool in real-world projects.

### *8.2.3 Suggested Time Frame for Implementation*

The recommended implementation involves the possible modification of the ODOT's technical documents. Therefore, this time frame cannot be determined at the time of submitting this report.

### *8.2.4 Expected Benefits from Implementation*

With the aid of the TAEHIA tool, the project-level PM<sub>2.5</sub> conformity analysis could be conducted effectively and efficiently. Specifically, the user's time and effort can be saved when he/she 1) defines analysis links and receptors through the TAEHIA graphic interface; 2) converts traffic and non-traffic data to MOVES and AERMOD inputs; 3) converts MOVES outputs to AERMOD inputs; and 4) analyzes AERMOD outputs to determine the conformity of a study area. With the use of the TAEHIA, it will become possible to identify the traffic operating factors and associated criteria for requiring the not-spot analysis. Finally, this study provides an opportunity to build up the interdisciplinary knowledge base of PM<sub>2.5</sub> emission-related problems in an integrated manner.

### *8.2.5 Potential Risks and Obstacles to Implementation*

The TAEHIA is incorporated in the ArcGIS environment. The user needs to purchase the ArcGIS license in order to implement the TAEHIA functions. In addition, basic ArcGIS skills are required to operate the TAEHIA. The user may need training on the application of the ArcGIS software. Additionally, the TAEHIA tool must be presented to and approved by the resource agencies (FHWA, USEPA, and OEPA) prior to use on ODOT projects.

### *8.2.6 Strategies to Overcome Potential Risks and Obstacles*

For the first risk, the strategy is to develop upgraded TAEHIA version that can be plug into some open source GIS tools, such as QGIS, GRASS GIS and uDig. For the second risk, the most effective strategy is to incorporate the GIS skills needed in the TAEHIA analysis in the TAEHIA user manual and training materials so that the user can easily find help from these documents.

### *8.2.7 Potential Users and Other Organizations that May be Affected*

The potential users include the ODOT Office of Traffic Engineering, the state and local traffic engineers and the state and local EPA. Also, consulting companies might benefit from this research by using the TAEHIA in their project-level PM<sub>2.5</sub> conformity analysis.

### *8.2.8 Estimated Costs of Implementation*

The TAEHIA software may be obtained from ODOT free of charge. The cost for implementation is based on the price of the ArcGIS license and the cost of attending software trainings.

### *8.2.9 Potential Application with Advanced Technology or System*

The TAEHIA tool may be used to evaluate the environmental effects of the Intelligent Transportation Systems, such as ramp metering, variable message sign and coordinated signal system.

## APPENDIX 1: TAEHIA REGIONAL ANALYSIS MODULE

Besides the project-level module, TAEHIA also offers a regional analysis module that can be used for regional PM<sub>2.5</sub> analysis. Details of the TAEHIA regional module is described in this appendix.

### A1.1 Basic Functions of TAEHIA Regional Module

The transportation conformity provisions of the Clean Air Act Amendments of 1990 require that the MPO for a study region makes a determination that the region's transportation plan, program and projects conform to applicable State Implementation Plans (SIPs). In particular, the emissions, taken as a whole from the plan, program and projects will not negatively impact the region's ability to meet the NAAQS deadlines. Conformity to a SIP means that the region's transportation plan and program 1) will not cause any new violations of the NAAQS; 2) will not cause any worsening of existing violations; and 3) will not delay efforts to attain the NAAQS in a timely manner. This demonstration is conducted by comparing motor vehicle emissions estimates for specific analysis years to the motor vehicle emissions budgets contained in the applicable SIP (U.S. EPA, 2012b).

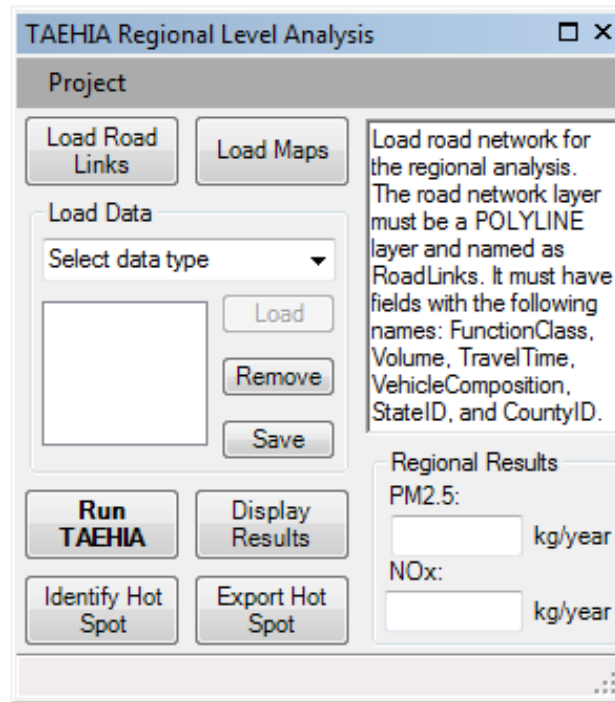
To perform the PM<sub>2.5</sub> conformity analysis for a study region, the U.S. EPA has recommended that both direct and indirect PM<sub>2.5</sub> emissions should be counted (U.S. EPA, 2012a). As stated by the U.S. EPA regulation, NO<sub>x</sub> is usually the only component of indirect PM<sub>2.5</sub> emissions. Once the overall quantity of the direct and indirect PM<sub>2.5</sub> emissions are calculated for the regional, the estimated PM<sub>2.5</sub> is compared to the PM<sub>2.5</sub> budget regulated by the SIP. If the modeled quantity is less than the budget, the study region conforms to the regional PM<sub>2.5</sub> requirements.

To conduct the regional conformity analysis, user needs to prepare the regional level inputs for MOVES. Consequently, the total direct and indirect PM<sub>2.5</sub> quantity of the region is estimated by using the MOVES regional analysis model. Usually, the regional inputs are prepared based on TDF analysis results. User needs to extract data from TDF output maps and calculated tables for MOVES inputs.

The regional analysis process is simplified by using TAEHIA. In the TAEHIA system, user only needs to input the TDF output maps and the non-traffic data into TAEHIA database by using the TAEHIA data import functions. Then, the MOVES inputs are automatically prepared within the TAEHIA. Once the data input is done, the TAEHIA will execute MOVES model and get analysis results from the MOVES output database.

The TAEHIA regional analysis module is incorporated in the ArcGIS platform. The module's user interface is shown by Figure A1-1. In the user interface, the TDF maps can be loaded by using Load Road Links button. Load Maps button is used to load other geometry feature classes, such as background map and study boundary into ArcGIS. In the Load Data panel, the non-traffic data, such as fuel, meteorology and age distribution of the fleet, can be selected and input into the TAEHIA database. When the TDF outputs and non-traffic data are input, user can click Run TAEHIA button to execute the regional conformity analysis. After the analysis is done, the total annual quantity of direct PM<sub>2.5</sub> emission and indirect PM<sub>2.5</sub> emission (NO<sub>x</sub>) are shown at the lower right corner of the window. The analysis results can be visualized by clicking Display Results button. In addition to helping identify the regional transportation conformity, the TAEHIA regional module can perform an algorithm to identify PM<sub>2.5</sub> hot-spots for project-level analysis. This function can be activated by clicking Identify Hot Spot button.





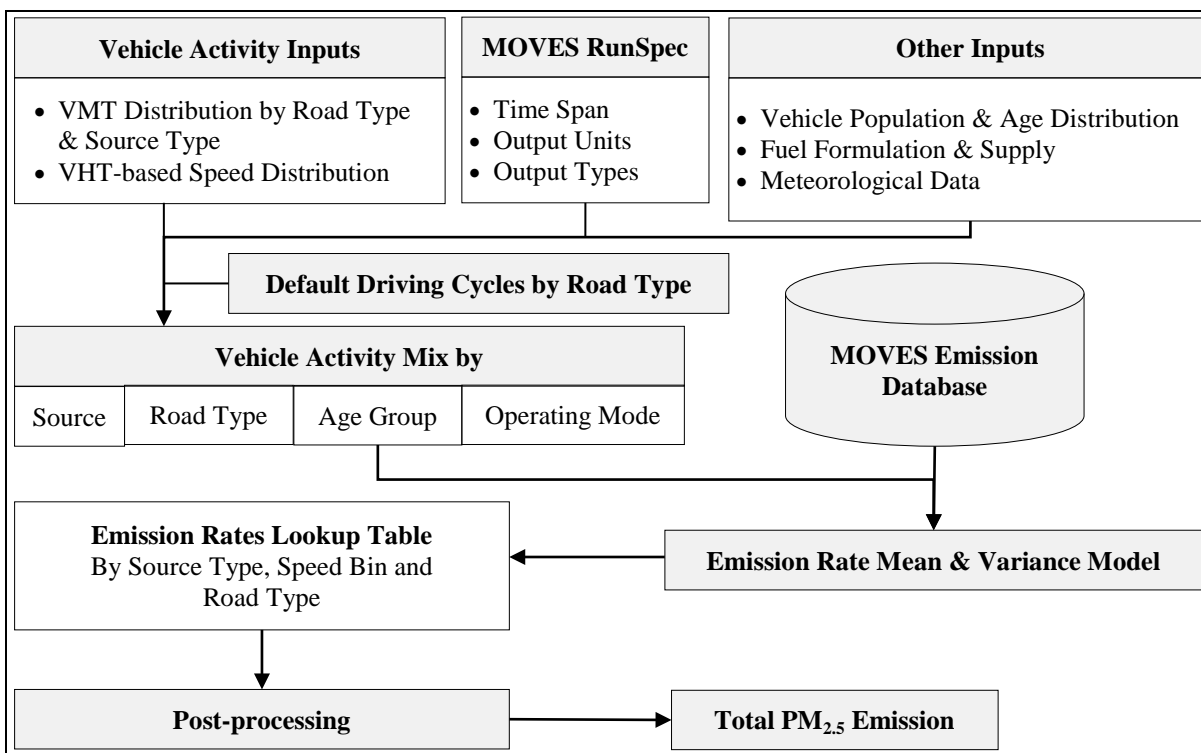
**Figure A1-1 User interface of TAEHIA regional module**

### **A1.2 Conducting Regional PM<sub>2.5</sub> Conformity Analysis by Using TAEHIA**

At regional level conformity analysis, Vehicle Mile Traveled (VMT) distribution by road type and source type, Vehicle Hour Traveled (VHT)-based speed distribution are vehicle activity inputs for the MOVES model. Non-traffic inputs include vehicle age distribution, meteorology data, fuel supply and formulation. The vehicle activity inputs are converted into the vehicle activity mix by applying the default driving cycles which are predetermined in the MOVES database. Once the vehicle activity mix by source, road type, age group and operating mode is generated, MOVES will correlate each of the activity mix to its emission database and then generate an emission rate lookup table by source type, speed bin and road type. In order to get the total amount of emission, a post-processing procedure is necessary by using the emission rate per VMT multiply by the VMT. The MOVES process of estimating total PM<sub>2.5</sub> emission for a regional is shown by Figure A1-2.

Based on the MOVES process, the steps of conventional method in conducting regional conformity analysis and the steps of TAEHIA method are summarized in Table 1-1. The advantage of using the TAEHIA tool is also summarized in Table A1-1.





**Figure A1-2 MOVES process of estimating regional PM<sub>2.5</sub> emission**

**Table A1-1 Steps of conducting regional PM<sub>2.5</sub> conformity analysis**

| Conventional Method   | TAEHIA Method  | Comments  |
|---|--|---|
| <b>Step 1:</b> Preparing non-traffic input data for MOVES. Datasets include age distribution, temperature and humidity, fuel supply and fuel formulation.   | <b>Step 1:</b> Same as Step 1 of the conventional method.  | N/A.  |
| <b>Step 2:</b> Get traffic data from TDF results. TDF data includes traffic volume, average speed and vehicle classification of each road link. It also includes length, capacity and function class of each road link.           | <b>Step 2:</b> Import TDF results to TAEHIA database. The TDF data must include following fields: link ID, link function class, average speed, and traffic volume. | Traffic data obtained from the TDF analysis is converted to the MOVES inputs automatically by TAEHIA.                   |
| <b>Step 3:</b> Prepare inputs for MOVES regional analysis. VMT distribution is prepared based on traffic volume and length of the road. VHT-based speed distribution is estimated based on traffic volume, link length and speed. | <b>Step 3:</b> Import non-traffic data to TAEHIA database and execute TAEHIA analysis.   | The MOVES analysis is automatically performed by TAEHIA.  |
| <b>Step 4:</b> Setup MOVES RunSpec file and input traffic and non-traffic data into MOVES database. Execute MOVES analysis.   | <b>Step 4:</b> Get results from TAEHIA user interface and visualize results in the map.  | The total emission quantity is automatically calculated by TAEHIA. The result map is automatically generated by TAEHIA. |
| <b>Step 5:</b> Get results from MOVES database  |  |   |

| Conventional Method   | TAEHIA Method   | Comments |
|---|---|----------|
| and post-process results to get total emission quantity.  |   |          |
| <b>Step 6:</b> Determine conformity of the study region based on the estimated emission quantity and the emission budget. | <b>Step 5:</b> Same as Step 6 of the conventional method. | N/A.     |

### A1.3 Development of TAEHIA Regional Module

Data flows of the TAEHIA regional analysis module are shown by Figure A1-3. Functions of the TAEHIA regional module are represented by circles in the gray area. Functions of preparing MOVES input database, automatically executing MOVES and visualizing link based emission quantity are similar with the corresponding functions in the TAEHIA project-level module. The hot-spots are identified based on the current ODOT criteria (AADT 125,000 and 10,000 truck traffic).

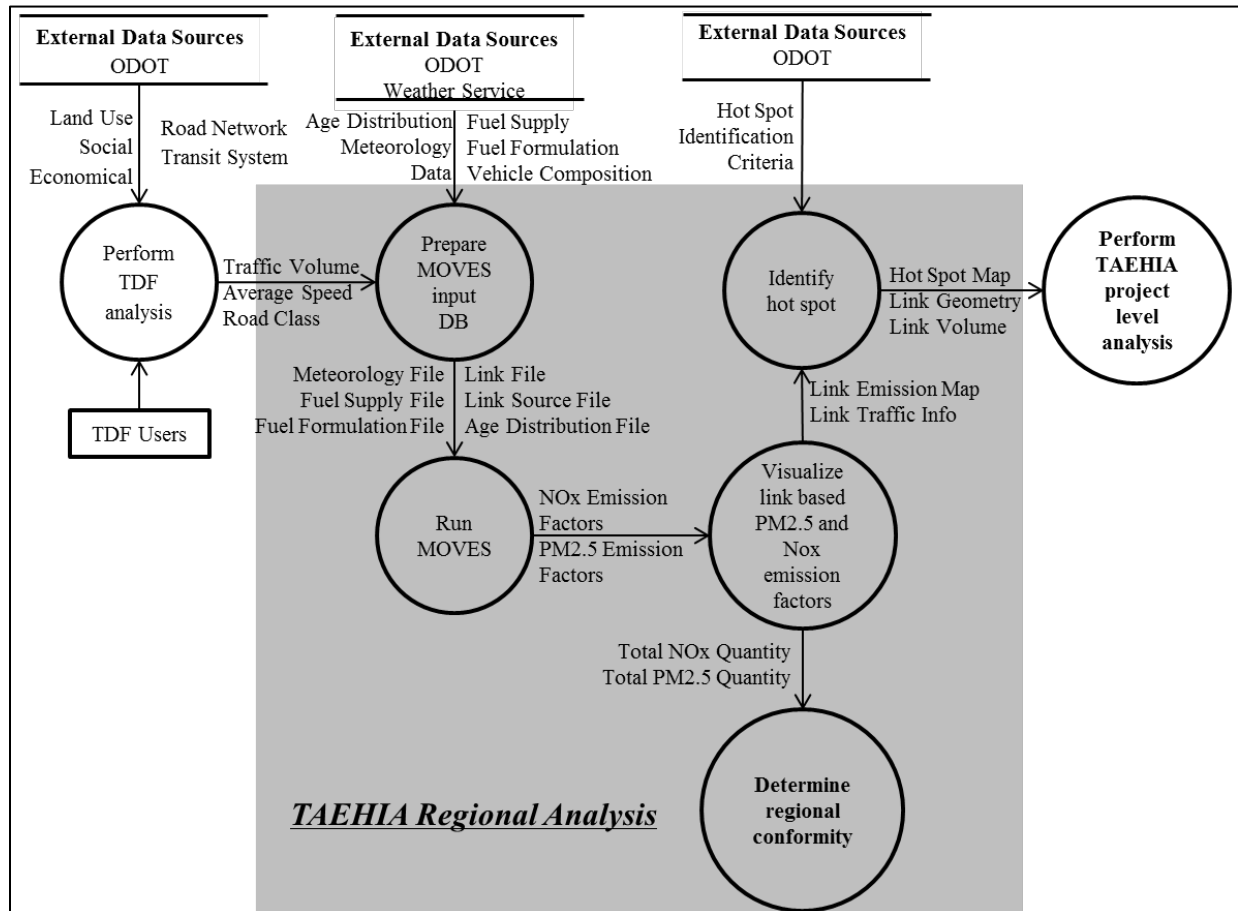


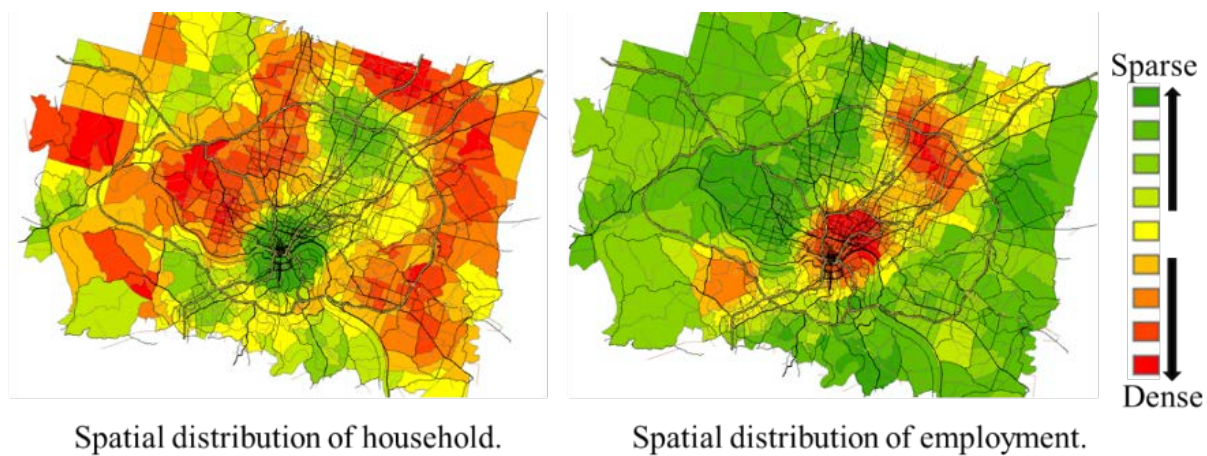
Figure A1- 3 Data flows of TAEHIA regional module.

#### A1.4 Case Study of TAEHIA Regional Analysis

In this case study, effects of land use pattern on regional  $PM_{2.5}$  emissions are analyzed in TAEHIA. Hamilton County, Ohio is selected as the study region. Regional  $PM_{2.5}$  quantity, link based  $PM_{2.5}$  quantity and hot-spots are identified in the case study.

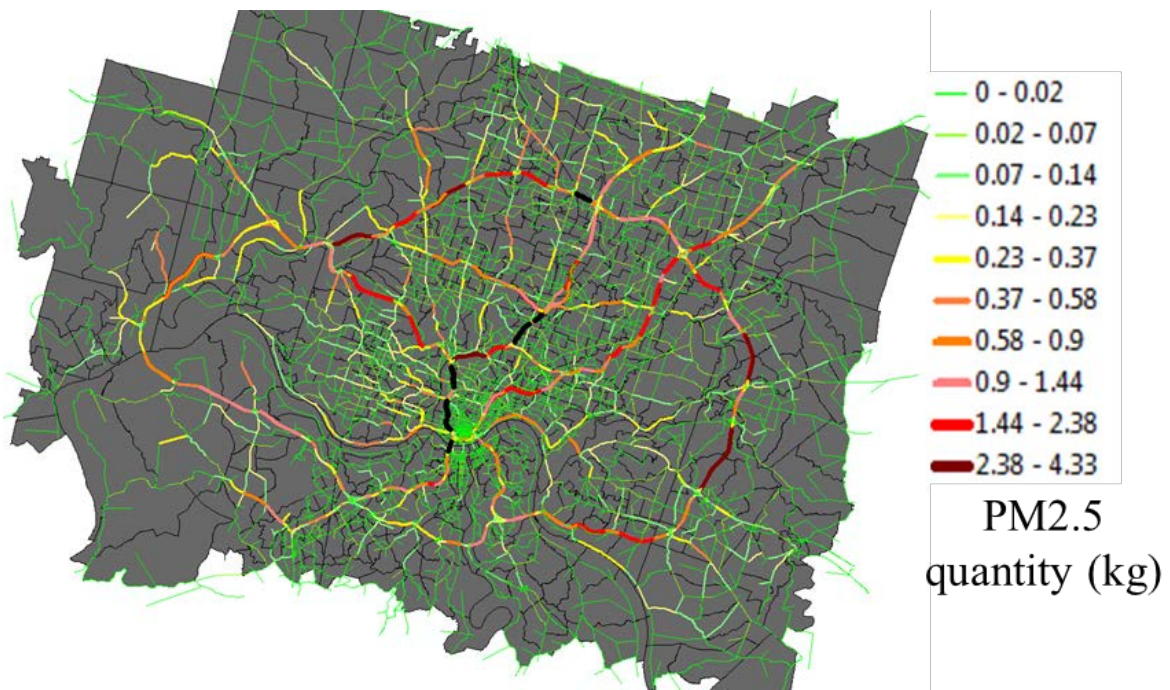
The spatial distribution of household and employment is shown by Figure A1-4. A spatial statistical parameter named  $z$  score is used to describe the density of the number of household and employment in each TAZ (traffic analysis zone). In statistics, the  $z$  score is the (signed) number of standard deviations an observation or datum is above the mean. Thus, a positive standard score represents a datum above the mean, while a negative standard score represents a datum below the mean. It is a dimensionless quantity obtained by subtracting the population mean from an individual raw score and then dividing the difference by the population standard deviation. A  $z$  score of 0 means the score is the same as the mean. A  $z$  score can also be positive or negative, indicating whether it is above or below the mean and by how many standard deviations.

In Figure A1-4,  $z$  score of each TAZ is visualized by using different colors. The positive  $z$  score is represented by red color and negative score by green color. The darker red a TAZ becomes, the denser the population or employment is at the TAZ. It can be found in the study area that there are three employment centers in the study region. The household is spatially distributed around the employment centers.

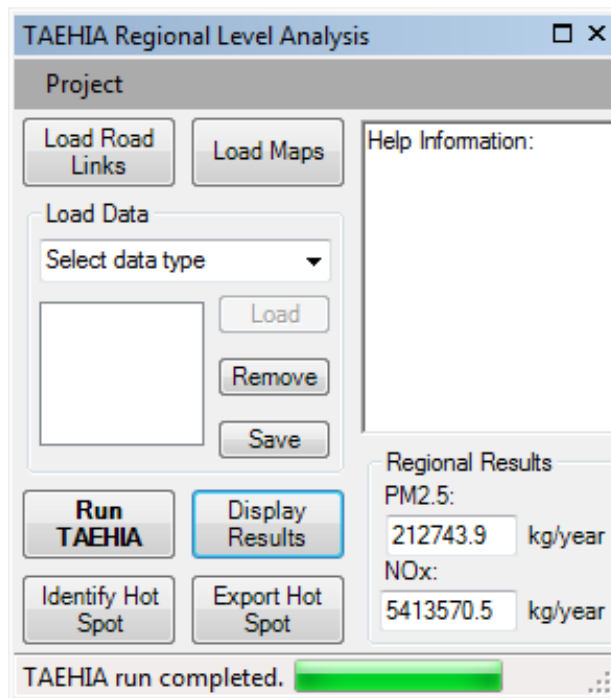


**Figure A1-4 Spatial distribution of household and employment of the study area**

After the TAEHIA analysis, the effects of the spatial distribution of employment and household on regional  $PM_{2.5}$  emission are estimated. As shown by Figure A1-5, the quantity of  $PM_{2.5}$  emission on each roadway link is estimated. Basically, the emission contribution of major freeways connecting household centers and employment centers is large. In addition to the link-based emission, the total emission of the study region is also estimated (as shown at the lower right corner of Figure A1-6). The results can be directly compared to the SIP budget and used to determine if the study region meets the conformity requirements or not. Moreover, the hot-spots (black solid lines) of the study region are also identified based on the AADT and truck traffic criteria. The hot-spots can be further analyzed in the project-level analysis.



**Figure A1-5 Link-based emission quantity of the study region.**



**Figure A1-6 Total emission quantity of the study region.**

## BIBLIOGRAPHY

- Bachman, W., Sarasua, W., Hallmark, S., Guensler, R. 2000. Modeling Regional Mobile Source Emissions in a Geographic Information System Framework. Transportation Research Part C 8, 205-229.
- Beaton, J. L. Skog, B. J., Shirley, E., C., Ranzieri, A. J., 1972. Mathematical approach to estimating highway impact on air quality, Report FHWARD-72-36, Prepared for Federal Highway Administration, Washington, DC.
- Benson, P. E., 1979. CALINE3-a versatile dispersion model for predicting air pollutant levels near highways and arterial streets. Repeort FHWA-CA-TL-79-23, Prepared for California Department of Transportation, Sacramento, CA.
- Benson P. E., 1984. CALINE4-a dispersion model for predicting air pollutant concentrations near roadways. Report FHWA-CA-TL-84-15, Prepared for California Department of Transportation, Sacramento, CA.
- Benson, E.P., 1992. A review of the development and application of the CALINE3 and 4 models. Atmosphere Environment 26B (3), 379-390.
- Broderick B.M., O'Donoghue R.T., 2007. Spatial variation of roadside C2-C6 hydrocarbon concentrations during low wind speeds: Validation of CALINE4 and COPERT III modeling. Transportation Research Part D 12, 537-547.
- California EPA, 2011. EMFAC2011-LDV users' guide. California Environmental Protection Agency.
- California Department of Transportation (CDOT), 1986. CALINE4-A dispersion model for predicting air pollution concentrations near roadways. California Department of Transportation, Sacramento, CA (FHWA/CA/TL-84/15).
- Cambridge Environmental Research Consultants (CERC), 2011. ADMS-Roads, an air quality management system, user guide, version 3.1. Cambridge Environmental Research Consultants, Cambridge, UK.
- Chamberlin, R., Swanson, B., Talbot, E., Dumont, J., 2011. Utilizing MOVES' link drive schedule for estimating project-level emissions. Presentation at the TRB Workshop on Integrating MOVES with Transportation Micro-simulation Models.
- Cimorelli, A.J., Perry, S.G., Venkatram, A., Weil, J.C., Paine, R.J., Wilson, R.B., Lee, R.F., Peters, W.D., Brode, R.W., 2005. AERMOD: a dispersion model for industrial source applications. Part I: general model formulation and boundary layer characterization. Applied Meteorology, 44, 682-693.
- Esworthy, R., 2012. 2006 National Ambient Air Quality Standards (NAAQS) for fine particulate matter (PM<sub>2.5</sub>): designating nonattainment areas. Report R40096, Prepared for Members and Committees of Congress.
- Frey, H.C., Roupail, N. M. and Zhai H., 2006. Link-based emission factors for heavy-duty diesel trucks based on real-world data. Transportation Research Record 2058, 23-32.
- Frey, H. C., Roupail, N. M. Zhai H., 2006. Speed- and facility-specific emission estimates for on-road light-duty vehicles on the basis of real-world speed profiles. Transportation Research Record 1987, 128-137.

- Fulper, C., Hart, C., Warila, J., Koupal, J., Kishan, S., Sabisch, M., DeFries, T., 2011. Development of real-world data for MOVES Development: The Houston Drayage Activity Characterization Study. Presentation at the Sunday Workshop #137 at 90<sup>th</sup> TRB Annual Meeting, Sunday Workshop #137.
- Ganguly, R., Broderick M.B., 2009. Development of models for predicting roadside nitrogen dioxide concentrations evaluation against datasets measure in Dulin, Ireland. *Transportation Research Part D* 14, 231-239.
- Ganguly, R., Broderick, M.B., 2010. A hybrid model for better predicting capabilities under parallel wind conditions for NO<sub>x</sub> concentrations from highways in Ireland. *Transportation Research Part D* 15, 513-521.
- Hatzopoulou, M., Santos, B., and Miller, E.J., 2008. Developing regional 24-hour profiles for link based, speed-dependent vehicle emissions and zone-based soaks. In 87<sup>th</sup> Transportation Research Board Annual Meeting, in Washington (No. 08-1157).
- Heist D., Isakov V., Perry S., Snyder M., Venkatram A., Hood C., Stocker J., Carruthers D., Arunachalam S., Owen R.C., 2010. Estimating near-road pollutant dispersion: A model inter-comparison. *Transportation Research Part D* 25, 93-105.
- Holmes N.S., Morawska L., 2006. A review of dispersion modeling and its application to dispersion of particles: An overview of different dispersion models available. *Atmospheric Environment*, 40, 5902-5928.
- Johansson, C., Norman, M., Gidhagen, L., 2007. Spatial & temporal variations of PM10 and particle number concentrations in urban air. *Environmental Monitoring and Assessment* 127, 477-487.
- Kanaroglou, P. S., Buliung, R. N., 2008. Estimating the contribution of commercial vehicle movement to mobile emissions in urban areas. *Transportation Research Part E*, 42(2), 260-276.
- Kumar, P., Pennell, P., Britter, R., 2008. Effect of wind direction and speed on the dispersion of nucleation and accumulation mode particles in an urban street canyon. *Science of the Total Environment* 402, 82-94.
- Kumor, A., Dlxtt, S., Varadarajan, C., Vijayan, A., Masuraha, A., 2006. Evaluation of the AERMOD dispersion model as a function of atmospheric stability for an urban area. *Environmental Progress* 25(2), 141-151.
- Lin, J., Chiu, Y. C., Bai, S., and Vallamsundar, S., 2011. Integration of MOVES and dynamic traffic assignment models for fine-grained transportation and air quality analyses. Presentation at the Sunday Workshop #137 at 90<sup>th</sup> TRB Annual Meeting, Sunday Workshop #137.
- Luhar, A.K., Patil, R., 1989. A general finite line source model for vehicular pollution dispersion. *Atmospheric Environment* 23, 555-562.
- Marmur, A., Mamane, Y., 2003. Comparison and evaluation of several mobile-source and line-source models in Israel. *Transportation Research Part D* 8, 249-265.
- McHugh, C.A., Carruthers, D.J., Edmunds, H.A., 1997. ADMS-Urban: an air quality management system for traffic, domestic and industrial pollution. *International Journal of Environment and Pollution* 8, 437-440.

- Nair, H. S., Bhat, C. R., 2000. VMT-mix modeling for mobile source emissions forecasting: formulation and empirical application. *Transportation Research Record*, 1738, 0361-1981.
- Nemalapuri, K.V., 2010. Impact of traffic operations on carbon monoxide emissions analysis. M.S. Thesis, University of Cincinnati.
- Oettl, D., Kukkonen, J., Kukkonen, J., Almbauer, A.R., Sturm, P.J., Pohjola, M., Härkönen J., 2001. Evaluation of a Gaussian and a Lagrangian model against a roadside data set, with emphasis on low wind speed conditions. *Atmospheric Environment* 35 (12), 2123-2132.
- Oge, M. T., 2010. Official release of the MOVES2010 Motor Vehicle Emissions Model for emissions inventories in SIPs and transportation conformity. Report FRL-9121-1, Prepared for U.S. Environmental Protection Agency.
- Ogulei, D., Hopke, P. K., Chalupa, D. C., Utell, M.J., 2007. Modeling source contributions to submicron particle number concentrations measured in Rochester, New York. *Aerosol Science and Technology*, 41, 179–201.
- Ohio Department of Transportation (ODOT), 2010. Environmental policy section of air quality and PM<sub>2.5</sub> [conformity process flowchart](http://www.dot.state.oh.us/Divisions/Planning/Environment/NEPA_policy_issues/AIR_QUALITY/Pages/default.aspx). Accessible at [http://www.dot.state.oh.us/Divisions/Planning/Environment/NEPA\\_policy\\_issues/AIR\\_QUALITY/Pages/default.aspx](http://www.dot.state.oh.us/Divisions/Planning/Environment/NEPA_policy_issues/AIR_QUALITY/Pages/default.aspx).
- Qu, Y., Holmén, B., Ravishanker, N., 2008. Predicting light-duty gasoline vehicle on-road particle number concentrations from gas concentrations using time-series cross-section regression. In 87th Transportation Research Board Annual Meeting (No. 08-1047).
- Petersen, W.B., 1980. User's Guide for HIWAY-2, highway air pollution model, 3-17. EPA-600/8-80-018, Prepared for U.S. Environment Protection Agency, Research Triangle Park, NC.
- Scora, G., Barth, M., 2006. Comprehensive modal emissions model (CMEM), version 3.01 user's guide. University of California, Riverside Center for Environmental Research and Technology.
- Snyder, G.M., Venkatram, A., Heist, K.D., Perry, G.S., Petersen, B.W., Isakov V., 2013. RLINE: A line source dispersion model for near-surface releases. *Atmospheric Environment* 77, 748-756.
- Snyder G.M., Heist K.D., 2013. User's guide for RLINE Model Version 1.2. Prepared for U.S. Environment Protection Agency, Research Triangle Park, NC.
- Snyder, W.H., Thompson, R.S., Eskridge R.E., Lawson E.R., 1985. The structure of the strongly stratified flow over hills: dividing streamline concept. *Journal of Fluid Mechanics* 152, 249-288.
- Song, G., Yu, L., Wang, Z., 2007. A practical modeling approach for evaluation of fuel efficiency for road traffic. In Transportation Research Board 87th Annual Meeting (No. 08-0228).
- Transportation Research Board (TRB), 2010. Highway Capacity Manual 5<sup>th</sup> Edition. National Research Council, Washington, DC.
- Turner, D.B., 1970. Workbook of Atmospheric Dispersion Estimates. AP-26, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.



- U.S.A. California Department of Transportation. (1986). CALINE4 - A Dispersion Model for Predicting Air Pollution Concentrations Near Roadways. California: Department of Transportation. (Report Number – FHWA/CA/TL-84/15).
- U.S. EPA, 2001. User's guide to MOBILE6 printed on recycled paper mobile source emissions factor model. U.S. Environmental Protection Agency (No. EPA420-D-01-002a).
- U.S. EPA, 2003. User's Guide to MOBILE6.1 and MOBILE6.2. U.S. Environmental Protection Agency (No. EPA420-R-03-010).
- U.S. EPA, 2004a. AERMOD: description of model formulation. U.S. Environmental Protection Agency (No. EPA-454/R-03-004).
- U.S. EPA, 2004b. User's guide for the AMS/EPA regulatory model-AERMOD. U.S. Environmental Protection Agency (No. EPA-454/B-03-001).
- U.S. EPA, 2006. Implementation Guidance for the 2006 24-Hour Fine Particle (PM<sub>2.5</sub>) National Ambient Air Quality Standards (NAAQS). U.S. Environmental Protection Agency.
- U.S. EPA, 2010a. Motor Vehicle Emission Simulator (MOVES) user guide for MOVES 2010a. U.S. Environmental Protection Agency (No. EPA-420-B-10-036).
- U.S. EPA, 2010b. Transportation Conformity Guidance for Quantitative Hot-spot Analyses in PM<sub>2.5</sub> and PM<sub>10</sub> Nonattainment and Maintenance Areas. U.S. Environmental Protection Agency (No. EPA-420-B-10-040).
- U.S. EPA, 2011. Potential Changes in Emissions Due to Improvements in Travel Efficiency. U.S. Environmental Protection Agency (No. EPA-C-06-094).
- U.S. EPA, 2012a. Office of Transportation and Air Quality. Motor Vehicle Emission Simulator (MOVES) – User Guide for MOVES2010b. U.S. Environmental Protection Agency (No. EPA-420-B-12-001b).
- U.S. EPA, 2012b. Office of Transportation and Air Quality. Policy Guidance on the Use of MOVES2010 and Subsequent Minor Revisions for State Implementation Plan Development, Transportation Conformity, and Other Purposes. U.S. Environmental Protection Agency (No. EPA-420-B-12-010).
- U.S. EPA, 2014. Office of Transportation and Air Quality. Project-Level Conformity and Hot-Spot Analyses. U.S. Environmental Protection Agency. Accessed at <http://www.epa.gov/oms/stateresources/transconf/projectlevel-hotspot.htm>.
- Ward, C.E., Charles, E., Andrew, J.R., Shirley, C.E., 1976. CALINE2-an improved microscale model for the diffusion of air pollutants from a line source. Transportation Research Board Special Report 167, 97-120.
- Willis, G.E., Deardorff, J.W., 1981. A Laboratory study of dispersion in the middle of the convectively mixed layer. Atmospheric Environment 15, 109-117.