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16. Abstract

Transportation related emissions are one of the dominant contributing sources of air pollutants today. Considering the negative impacts of transportation related emissions on our social and economic environment, extensive efforts have been made by researchers and practitioners attempting to find solutions to reducing emissions. In order to synthesize these research efforts, various reviews of relevant studies have been conducted by researchers. However, because of the diversity of the topics, most of existing reviews have only focused on specific and narrowed areas. Further, none of the existing reviews has attempted to summarize the researchers' personal opinions on the current research and their prospects of the future research directions. Therefore, this report is intended to fill this gap by conducting a comprehensive review of the research on transportation related emissions and implementing an extensive survey to the transportation emission professionals. In the report, a review of existing research and developments on each of the emission related topics is provided, which is followed by a presentation of the respective survey results and analysis. Future research directions in this field are presented based on the findings of the review and results of the survey. As a conclusion, current research status is summarized for each topic and recommendations are made for future research directions.

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A Synthesis of Transportation Emissions Research: Current Status and Future Directions

by

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and
Qinyi Shi

Report SWUTC/08/473700-00049-1

Sponsored by the
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ABSTRACT

Transportation related emissions are one of the dominant contributing sources of air pollutants today. Considering the negative impacts of transportation related emissions on our social and economic environment, extensive efforts have been made by researchers and practitioners attempting to find solutions to reducing emissions. In order to synthesize these research efforts, various reviews of relevant studies have been conducted by researchers. However, because of the diversity of the topics, most of existing reviews have only focused on specific and narrowed areas. Further, none of the existing reviews has attempted to summarize the researchers' personal opinions on the current research and their prospects of the future research directions. Therefore, this report is intended to fill this gap by conducting a comprehensive review of the research on transportation related emissions and implementing an extensive survey to the transportation emission professionals. In this report, a review of existing research and developments on each of the emission related topics is provided, which is followed by a presentation of the respective survey results and analysis. Future research directions in this field are presented based on the findings of the review and the results of the survey. As a conclusion, current research status is summarized for each topic and recommendations are made for future research directions.

EXECUTIVE SUMMARY

Transportation related emissions are one of the dominant contributing sources of air pollutants today. Considering the negative impacts of transportation related emissions on our social and economic environment, extensive efforts have been made by researchers and practitioners attempting to find solutions to reducing emissions. However, because of its cross-disciplinary nature, most of existing reviews have only focused on specific and narrowed areas. Further, none of the existing reviews has attempted to summarize the researchers' personal opinions on the current research and their prospects of the future research directions. Therefore, this study is intended to fill this gap by conducting a comprehensive review of the research on transportation related emissions and implementing an extensive survey to the transportation emission professionals.

In order to provide a full-scale review of the research and development accomplishments related to transportation emission models, the research is carried out based on the following methodology. First, the study conducts an extensive review of the history and development of research on transportation related emissions by synthesizing existing literatures. Review of the state-of-the-art/practice helps categorize research subjects, methods and findings of current literatures and select corresponding technologies, models, and issues to represent each category. The survey topics are thereafter generated based on the defined categories. Then, the study converts the selected topics into survey questions and designs the statement of each question in an easy-to-understand manner. The format of the survey questionnaires is designed afterwards. Further, the study develops a contact inventory of the survey targets, which summarizes the names and contact information of emission professionals based on their research publications and working disciplines. When the survey preparation work is done, the authors distribute the survey and collect responses. The survey is distributed by web and email formats and the responding data are stored and sent back to the research team using a commercial service. Subsequently, the study analyzes the survey results and presents them in various formats. Finally, the study synthesizes the findings based on existing literatures and analyzing the results based on the survey, which provides the current research status and professionals' preference while also makes a prediction on some potential research directions for the future.

The following conclusions are reached based on the research:

The transportation emission measurement system combines both laboratory and field test methods. It is able to serve the need to measure emissions from a general fleet and individual objectives. The measurement system is experiencing a refinement process from laboratory testing to real-world data collection.

Based on the review, the emission modeling system has the ability to model all regional, segment/facility, and individual levels emissions. Although there are several types of emission models, such as travel based models, fuel based models, and instantaneous models, EPA's old and new generation models are still keeping the status as a reference to emission modeling research and practice. Especially the new generation model, MOVES, will be able to serve the need of all levels.

According to the review, the emission reduction activities are required by laws and are administrated by federal and state governments. The reduction activities need to involve efforts from governments, manufacturers, and customers. The actions make credits in terms of reducing criteria pollutants and GHG emissions.

Transportation emission related issues cover a wide range. The research and practice territory of this topic keeps spreading. It is a multi-task to cover all intermodal emission controlling, impacts on air quality and environment, regulatory action, and economy impacts analysis. Transportation emission research is becoming a cross-disciplinary subject which combines transportation, planning, chemistry, and environmental studies.

In light of the findings and conclusions, the report makes three recommendations to the future studies of the transportation related emissions.

1. It is recommended that the emission modeling system be synthesized and a new generation of emission models be developed as soon as possible.

2. It is recommended that the transportation professionals be involved in a wider area of the emission studies other than only focusing on the on-road source emission measurement and modeling.
3. It is recommended that the responsible organizations encourage the public to pay more attention to the GHG emissions and energy efficiency in regards to the transportation emission reduction.

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CHAPTER 1: INTRODUCTION

Nowadays, environmental problems have become a critical threat to the creatures living on the earth. Among the environmental problems, the air quality issue is one of the most harmful matters to public health, environmental stability and global warming. As the principle contribution to the criteria pollutants and the Greenhouse Gas (GHG), transportation related emissions have been given significant recognition and the research in this area has gone through a remarkable development. However, because of its cross-disciplinary nature, research on transportation related emission has demonstrated certain limitations. The major limitations include: gaps between research fields, lack of understanding between research disciplines, the inadequacy of the comprehensive review of the existing research, and blurry projection of future research directions. The study in this report will focus on providing a full-scale synthesis of the research on transportation related emissions and present some first-hand ideas from emission professionals based on a survey.

1.1 Background of Transportation Related Emissions

Transportation related emissions refer to emission components generated by transportation activities. According to the nature of the emission components, transportation related emissions can be categorized as criteria pollutants and GHG emissions. The criteria pollutants are air contaminants that have significant threats to public welfare and human health, especially to the sensitive populations such as children and the elderly. Based on emission's impacts and characters, Environmental Protection Agency (EPA) sets primary and secondary standards to six air contaminates as criteria pollutants in its National Ambient Air Quality Standards (NAAQS, 1970). These containments are Ozone (O3), Particulate Matter (PM2.5-10), Carbon monoxide (CO), Sulfur dioxide (SO2), Nitrogen oxides (NOx), and Lead (Pb). Transportation related emissions are the dominant source of criteria air pollutants. In 2002, nationwide, transportation sources were responsible for 82% of CO, 56% of NO2, 12% of the Pb, and 5% of SO2 (Easter Research Group, 2003). These pollutants are the major constituent of smog that causes acid rains, visibility reduction, and severe health problems. While GHG are components of the atmosphere that contribute to the greenhouse effect, transportation related GHG emissions mainly refer to the carbon dioxide (CO_2) emissions. Transportation sector is accounted as the second largest source of CO_2 emissions in the U.S. It directly emitted approximately 27% of total U.S. GHG emissions in 2003 (EPA, 2003). The obvious trend of the global warming, which is caused by the GHG, is responsible for numerous environmental hazards, such as climate changing, more frequent natural disasters, disappearing glaciers, and raising sea levels. Other than the contribution to environmental problems, transportation related emissions have significant impacts on the economic aspect of the society as well. A National Academy of Sciences (NAS) study estimated that a nationwide 90% reduction in vehicle emissions from 1973 levels would save $1.6-8.8 billion/year in 1980 dollars.

In addition to the classification based on components, transportation related emissions could be categorized based on their sources. General transportation related sources are "on-road" or highway sources, which include vehicles used on roads for transportation of passengers or freight, and “non-road" sources, which include vehicles, engines, and equipment that are used or served the transportation purposes other than on-road. On-road sources are responsible for emissions from light-duty vehicles, heavy-duty vehicles, buses, and motorcycles that are used for transportation on the road. On-road vehicles may be fueled with gasoline, diesel fuel, or alternative fuels such as alcohol or natural gas. Non-road sources are responsible for emissions from aircraft, marine vessels, locomotives, and other non-road vehicles, engines & equipment such as port (airport and seaport) service equipment & vehicles and railway maintenance equipment that are considered to be part of the transportation system. Within the two broad categories, on-road sources contribute a larger part of the total emissions from the transportation sector. In 2000, on-road transportation sources accounted for 44% of CO emissions, 33% of NO_x emissions, and one percent of PM_{10} emissions (CCCEF, 2007a). Moreover, since on-road emissions usually occur in population dense areas and thus have heavier impacts on air quality, they are gaining more attention in emission research and regulation disciplines.

1.2 Status of Current Research on Transportation Related Emissions

1.2.1 Status of Current Research

As one of the principle causes to the air quality problems and global warming, transportation related emissions have been given significant recognition and the research in this area has gone through a remarkable development.

Existing emission related research covers a variety of research directions. With respect to on-road sources emissions, research has been conducted on emission measurement technologies, emission estimation models, and emission reduction strategies. Study on emission measurement technologies is the cornerstone of the entire on-road emission related research. Existing measurement technologies combining both laboratory and field test methods are able to measure emissions from individual vehicles and massive fleet. Widely adopted technologies include dynamometer & driving cycle testing, Inspection and Maintenance (I/M) programs, Remote Sensing Devices (RSD), and the Portable Emission Monitoring System (PEMS) (Corvalan & Vargas, 2003; OTAQ, 2004a; Vescio, 2002; Weaver & Petty, 2004). The emission modeling system for on-road emissions is composed of a number of models which can estimate and predict transportation emissions at all macroscopic (regional), mesoscopic (segment or facility), and microscopic (individual) levels. Travel-based emission models, fuel-based models, modal & instantaneous emission models, and emission estimation modules related to travel demand & traffic simulation models are four representative forms in terms of emission modeling (EPA, 2004a; EEA, 2000; Rakha & Ahn, 2004; Rakha, 2007). Research on emission reduction strategies serves a purpose to control and reduce emissions from on-road transportation related emission sources. Proposed reduction strategies and activities include vehicle design improvements, new energy technology, smoothing and reducing of traffic, I/M programs, and improving fuel economy (Griffith, 2007; Kear & Niemeier, 2004; Missouri I/M Group, 2005; EPA, 2004b). Strategies are developed and implemented with different levels of effectiveness applying to reduce criteria pollutants and GHG emissions.

Concerning the non-road transportation related emission sources, the studies are not as diverse or systematic as the research regarding on-road sources; the research is mainly conducted based on EPA's guidelines on the emission resources. For aviation sources, EPA publishes a regulatory support document to control air pollution from aircraft and aircraft engines and provides emission standards and test procedures for the aircraft and aircraft engines (EPA, 1997). For marine sources, EPA provides commercial marine emissions inventory and emission control guidance for marine diesel engines (Corbett & Fischbeck, 1998). For locomotive sources, EPA publishes a regulatory support document for locomotive emission standards (OMS, 1998). For non-road engines, EPA provides exhaust and evaporative emission factors for non-road emission modeling (OTAQ, 2005b).

In association with the air quality evaluation based on emissions from all sources, the research has been conducted on the sophisticated emission dispersion modeling (Coe, Eisinger, Prouty, & Kear., 1998). Most existing emission dispersion models are developed by EPA, and according to their accuracy and acceptance levels, the models are classified into four categories: preferred and recommended models, alternative models, screening models, and photochemical models. Accuracy of the dispersion model relies on the accuracy of the emission data.

In terms of the regulation and controls, research has been conducted on emission legislative actions, all-level government compliance programs and emission control assessment strategies. Legislative and regulatory action towards transportation related emissions defined the research area and directions. All emission research should comply with the laws and regulation requirements. Besides the general environmental statute, there are three air quality related legislative references: the Clean Air Act-Conformity, Clean Air Act-Sanctions and Congestion Mitigation & Air Quality Improvement (FHWA, 2007). Concerning the compliance, emission screening programs are developed under the regulation discipline.

In addition, existing research on transportation related emissions involves a participation of experts from various disciplines such as environmental engineering, chemical engineering, transportation engineering, transportation and land use planning, mechanical engineering, etc.

1.2.2 Problems of Current Research

Although the transportation related emission research has gained remarkable accomplishments, because of its cross-disciplinary nature, the existing research has demonstrated certain limitations. Major limitations include: gaps between research fields, lack of understanding between research disciplines, inadequacy of the comprehensive review of the existing research, absence of first-hand opinions from researchers, and the blurry projection of future research directions. Gaps between research fields are represented by the lack of connections between existing research efforts. For instance, the EPA provides the emission inventory development guidance for marine, on-road and non-road sources emissions, but there is no general guidance to generate inter-modal seaport and airport emission inventories. The lack of understanding between research disciplines is represented by a lack of cross disciplinary effort as researchers from different disciplines tend to focus only on specific areas. For instance, transportation engineers may focus only on the influence of different operational strategies on emissions, but might not be aware of the dispersion impacts of the emissions. Air quality experts may focus only on the dispersion of emissions on a road segment, but not pay attention to the impacts of operational strategies on the dispersions. The problem of inadequacy of the comprehensive review of the existing research is represented by the limited topic-by-topic review efforts. For instance, reviews of emission measurement technologies may be conducted, but the review tends to focus only on the existing measurement methodologies. It is usually not synthesized with other relevant topics such as emission modeling or dispersion. The problem of the absence of first-hand opinions from researchers is represented by the pure synthesized results from former studies. Most of the research efforts tend to summarize their "own" ideas instead of doing a direct survey on other experts' opinions. The problem of the blurry projection of future research directions is represented by a lack of forecasting. Most researchers prefer to summarize existing efforts instead of providing ideas of future research directions.

1.3 Research Objectives

In order to fill the gaps of existing research on transportation related emissions, the study in this report is intended to achieve the following objectives:

1. To build connections between research on emissions from transportation sources by synthesizing the studies and findings on different transportation modes.
2. To decrease lack of understanding between transportation research disciplines and air quality or regulation disciplines by integrating emission research studies in all fields of environmental engineering, chemical engineering, transportation engineering, transportation and land use planning, and mechanical engineering.
3. To provide a full-scale review of the existing research on transportation related emissions by providing both topic-by-topic and synthesized reviews of the studies.
4. To investigate and summarize first-hand opinions on research associated with transportation emissions from researchers by conducting a comprehensive survey among emission experts.
5. To project future emission research directions by examining review findings and survey results.

1.4 Outline of the Report

The studies of the report are divided into five chapters. In the first chapter, the report introduces the background of transportation related emissions and current status of the research on emissions, and presents objectives of the research. In the second chapter, the report sums up the existing review and summary efforts of the research on transportation emissions. In the third chapter, the report describes the design of the study. It presents the general methodology, methods of reviews on literatures and implementation process of a survey on transportation related emissions. In the fourth chapter, the report summarizes findings of the reviews based on literatures and the results based on survey. In the fifth chapter, the report concludes according to the findings and makes some recommendations for the future research on transportation related emissions.

CHAPTER 2: LITERATURE REVIEW

As discussed in Chapter 1, research on transportation related emissions is a complicated and cross-disciplinary study area. In order to fully understand the nature of this important research, a comprehensive review is necessary. This chapter will summarize the existing efforts on the review studies, and synthesize the existing research on the transportation related emissions. Generally, there are basically two types of review efforts: 1) Reviews and summaries conducted by authoritative agencies and research organizations, such as EPA, United States Department of Transportation (USDOT), Transportation Research Board (TRB) and The Coordinating Research Council (CRC). These reviews mainly focus on diversity related topics of the research on transportation emissions and provide a relatively systematic summary. 2) Reviews conducted by individual researchers. These reviews mainly focus on summarizing specific research topics with more details.

2.1 Summary and Review Efforts from EPA’S OTAQ

In the United States, EPA is playing a leading role in reviewing and summarizing the research on emissions and air quality. Inside EPA, the Office of Transportation and Air Quality (OTAQ), which is part of EPA's Office of Air and Radiation (OAR), is directly responsible for presenting and summarizing the findings and research on transportation related emissions. It provides comprehensive summaries of the current status of the research to both the public and researchers.

In its homepage, OTAQ describes its mission and presents several transportation related emission key topics to synthesize the research of emission and transportation (OTAQ, 2007a).

OTAQ describes its mission as to reconcile the transportation sector with the environment by advancing clean fuels and technology, and work to promote more livable communities (OTAQ, 2007b). To achieve the mission, OTAQ is assigned the following responsibilities: characterizing emissions from mobile sources (both on-road and non-road sources) and related fuels, developing programs for their control, including assessment of the status of control technology and in-use vehicle emissions; carrying out a regulatory compliance program, in coordination with the Office of Enforcement and Compliance Assurance (OECA), to ensure adherence of mobile sources to standards; fostering the development of the state I/M Programs, and implementing programs for the integration of clean-fueled vehicles into the market.

OTAQ presents a respectable amount of transportation emission related key topics to synthesize the research of emission and transportation, including: overview of pollutants and programs, consumer information, motor vehicles and engines, non-road engines, fuels and fuel additives, partnership, state and local transportation resources, and modeling test and research.

Overview of pollutants and programs shows information on how much air pollution and greenhouse gases are emitted by mobile sources, the programs OTAQ have undertaken to control these emissions, and the impact of those programs on air quality and climate change (OTAQ, 2007c).

Consumer information shows what consumers can do to help reduce air pollution and how to buy the cleanest, most fuel-efficient vehicle that meets consumers' needs (OATQ, 2007d).

Motor vehicles and engines provide information about highway vehicles (cars and light trucks, heavy trucks, buses, engines, and motorcycles) for their fuel economy, emission standards and regulations, emission recall programs, new vehicle certification and in-use vehicle compliance, I/M programs, diesel retrofit programs, evaluating the benefits of inventions designed to reduce emissions, and importing vehicles to the United States (OTAQ, 2007e).

Non-road engines, equipment and vehicles summarize emission standards and regulations, certification and compliance, and diesel retrofit programs on aircraft, locomotives, diesel and gasoline boats and ships, personal watercraft, lawn and garden equipment, agricultural and construction machines, and recreational vehicles (OTAQ, 2007f).

Fuels and fuel additives provide information on diesel, gasoline, and alternative fuels for mobile sources, fuel-quality control programs, requirements for registration and health effects testing of new fuels or fuel additives, and reporting forms (OTAQ, 2007g).

Partnership provides information about EPA's partnerships to reduce air pollution associated with transportation and other mobile sources. These programs include commuter choice, diesel retrofit, buying a cleaner car or truck, and other initiatives (OTAQ, 2007h).

State and local transportation resources provide information on the ties between land use, transportation planning, and air quality (OTAQ, 2007i). The topics include conformity, State Implementation Plans (SIP), transportation control measures, and available funding and grants for implementation of such programs.

Modeling, testing and research provide information on models for estimating emissions from highway vehicles, non-road sources, and fuels, how EPA tests and measures emissions, and the research into advanced technologies (OTAQ, 2007j).

The EPA's OTAQ summarizes the comprehensive, systematic and authoritative review of the research activities on transportation related emissions, but these reviews do not provide the latest academic research updates and researchers' personal responses and evaluation.

2.2 Summary and Review Efforts from USDOT'S CCCEF

The Center for Climate Change and Environmental Forecasting (CCCEF) is the focal point in the USDOT of technical expertise on transportation and climate change (CCCEF, 2007a). Through the strategic research, policy analysis, partnerships and outreach, CCCEF creates comprehensive and multi-modal approaches to reduce transportation-related greenhouse gases and to mitigate the effects of global climate change on the transportation network.

CCCEF reviews the transportation related activities and their contributions to the climate change by conducting emission inventory analysis (CCCEF, 2007b). It concludes that in contrast with trends in other air emissions, greenhouse gas emissions from transportation continue to rise, in large part because travel growth has outpaced improvements in the vehicle energy efficiency.

CCCEF sponsors and partners with a respectable amount of governmental and research agencies to conduct a unique transportation research perspective to federal climate change (CCCEF, 2007c). The research is classified into four categories. In the research category of impact of climate variability and change on transportation, studies such as "Effects of Sea Level Rise on National Transportation Infrastructure," "Transportation and Climate Change Study," "Impacts of Global Climate Change on Hydraulics and Hydrology and Transportation," and "Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study" are being sponsored by CCCEF to reveal the trend of climate change on transportation. In the research category of increasing energy efficiency and reducing greenhouse gas emissions, studies such as "Assessing State Long-Range Transportation Planning Initiatives in the Northeast for Climate Energy Efficiency Benefits," "Transportation Emissions Charges: Analysis of Costs to Achieve Emissions Reductions," "Fuel Options for Reducing Greenhouse Gas Emissions from Motor Vehicles," "Reducing the GHG & Air Quality Impacts of Freight Transportation" are being sponsored by CCCEF to propose solutions in terms of reducing and controlling GHG emissions. In the research category of modeling GHG emissions, studies such as "Holistic Comparative Analysis of Emissions from Aviation, Automobile, Marine, and Diesel Transports," "Alternative and Advanced Fuel and Vehicle Technology Modeling," and "Measuring the Greenhouse Gas Intensity of the Transportation Sector" are being sponsored by CCCEF to quantify the GHG emissions perspective to transportation sector. In the research category of institutional capacity building, CCCEF is still searching for appropriate projects to sponsor or to partner with.

In addition to driving the reduction of transportation related GHG emissions, CCCEF functions in coordinating with DOT-Federal Highway Administration (FHWA)'s Office of Natural Environment Air Quality (ONEAQ) and Office of Natural Environment Conformity (ONEC) to synthesize transportation related emissions study and control (CCCEF, 2007d). DOT-FHWA's ONEAQ and ONEC are joining together with EPA with respect to the air quality research and compliance.

CCCEF's summaries on transportation related GHG emissions are comprehensive and authoritative, but these reviews do not provide the latest research nor researchers' personal responses and evaluation.

2.3 Summary and Review Efforts from TRB'S ADC 20

TRB's Committee on Transportation and Air Quality (ADC20) is the committee in charge of promoting and updating transportation emission and air quality research in conjunction with the annual TRB meeting and sponsoring other transportation emission related events (TRB, 2007a). The most recent updated and reviewed topics by the committee include (TRB, 2007b):

- Exploring environment and economic implications of alternative fuels for aviation
- Air quality transformations around the world
- The future energy in transportation
- Assessing the impact of gas prices on transit ridership and enhancing regional transit planning
- Impacts of climate change on transportation infrastructure and systems
- Plug-in Hybrid opportunities and challenges
- Intermodal environmental analysis
- Opportunity to reduce diesel emissions
- Transportation ecology research and practices
- Transportation and environment in Asia and Latin America, etc.

As discussed above, the committee provides the latest updates on emission research by topics. However, the topics are not reviewed and synthesized nor does the committee provide researchers' personal opinions and ideas.

2.4 Summary and Review Efforts from CRC

CRC is a non-profit organization that directs, through committee action, engineering and environmental studies on the interaction between automotive equipment and petroleum products (CRC, 2007). The formal objective of CRC is to encourage and promote the arts and sciences by directing scientific cooperative research to develop the best possible combinations of fuels, lubricants, and the equipment in which they are used and to afford a means of cooperation with the government on matters of national interest within this field.

CRC holds an On-Road Vehicle Emissions Workshop annually. Participates of the workshop discuss mobile source emission and related topics during the meeting and CRC publishes a report of the workshop through the Journal of Air & Waste Management Association (Cadle et al., 2007; Cadle et al., 2006; Cadle et al., 2005; Cadle et al., 2003). Topics summarized at the workshops include: on-board emissions measurements, new emissions models, particulate matter (PM) emissions and measurement, diesel vehicle emissions, emissions measurement methods, fuel effects studies, emissions control measures, emission inventories, EPA's Motor Vehicle Emissions Simulator (MOVES) model, mobile source modeling: MOBILE 6 and modal models, fuel effects on vehicle emissions, unregulated emissions, etc.

Similar to TRB's Committee on Transportation and Air Quality, the reports generated by CRC are professional summaries of the latest developments. However, the reports only focused on the on-road emission resources, but do not cover other emission resources and territories such as emissions from aviation or marine sources, emission dispersion, emission project cost/benefit analysis, emission regulation and so on. It is also hard to reveal researchers' personal opinions and ideas.

2.5 Summary and Review Efforts from Individual Researchers

In addition to the reviews from above agencies, there are numerous review studies conducted by researchers related to transportation emissions.

An emission inventories assessment project reviewed applications of new technologies to improve accuracy, timeliness and completeness of emission inventories across North America. The motioned new technologies include: major reductions in the largest emissions sources, changes in manufacturing processes, industry types, vehicle technologies & metropolitan infrastructure, new remote platforms technologies for measuring source emissions and ambient pollutant concentrations, advances in information technologies which allow data to be shared quicker and easier. The information system will also improve the quantitative measures of inventory uncertainty (Miller, Hales, Hidya, & Kolb, 2006).

A driving cycle review project summarized the various drive cycles used for gasoline engine vehicles in Europe and the United States, and the impact of various factors and their influence on real-world emission levels (Samuel, Austin, & Morrey, 2002). The paper concluded that the amount of pollutant levels from automotive vehicles is underestimated because of the characteristics of the existing drive cycles. In the end, the paper proposed new driving cycles to the United States and Europe.

Vescio (2002) summarized the history and development of remote sensing technology and its applications in emission measurement. It presented three applications of the remote sensing technology and their recognition by EPA. It also summarized the applications of the remote sensing technology of each state in the United States.

An Internal Combustion Engine air toxic emissions research project for California Air Resources Board (CARB) comprehensively reviewed the dynamometer tests in measuring toxic and PM emissions of gasoline, diesel and alternative fueled light/heavy duty vehicles (Zhu, Durbin, Norbeck, & Cocker, 2004). Their review summarized hundreds of dynamometer tests with a variety of scenarios covering a wide range of years from early 1970s to early 2000s.

The summary and reviews efforts conducted by individual researchers were detailed, but only covered a specific area and did not provide researchers' personal opinions and prospect.

According to the literature reviews in this chapter, it is found that there is a lack of a general overview across all emission research disciplines and there has been little effort to investigate researchers' personal opinions in the area.

CHAPTER 3: DESIGN OF THE STUDY

3.1 General Methodology

In order to provide a full-scale review of the research and development accomplishments related to transportation emissions, a general methodology is first designed to investigate the status of relevant research. The general process of the research in this report consists of two primary components of the review: a review based on the literature, and a review based on a comprehensive survey. While the descriptions about the design of each component will be provided in later sections, the following provides an 8-step process about the general methodology.

In the first step, the study conducts an extensive review of the history and development of research on transportation related emissions by synthesizing existing literatures. During the review step, research subjects, methods and findings of current literatures are summarized into categories based on their histories, functions and influences. Then the study makes an abstract for each category and selects several technologies, models or issues to represent the category.

In the second step, the study generates survey topics based on the categories defined in Step 1. It analyzes the abstract and representative literatures within each category and then develops 3-5 topics from each category. It also adjusts the order of the topics to make them in a logical or chronicle way for the survey design later.

In the third step, the study converts the selected topics into survey questions. The study designs the statements of questions for each topic in an easy-to-understand manner, and arranges the choice of answers in a relatively random way to avoid repetition. The study then divides the survey into four major parts and provides instructions to each part.

In the fourth step, the study develops the format of the questionnaires for the survey. In order to provide a convenient access, the study designs a web-based survey. Respondents can enter the survey website by simply clicking the link. The survey procedure provided is in a "click and submit" fashion, which is easy to handle and saves time. For those who have difficulties entering the website, a PDF file is provided identical to the web survey, but which can be distributed and responded through emails. The PDF file is designed with real forms in it. Respondents can complete the survey in a similar fashion to the "click and submit" as the website users.

In the fifth step, the study develops a contact inventory of the survey targets. It summarizes the names and the contact information of the professionals who have had papers or research work published related to transportation emissions. It records authors and contact information of the emission project reports. It also includes contact information of the emission professionals from TRB's ADC 20.

In the sixth step, the study distributes the survey and collects responses. The study distributes the survey's web link by sending emails to professionals in the contact inventory. For the ones who have problems browsing the website, the PDF survey is then sent out as an attachment to the email. When website users respond to the survey, the data are stored and sent back to the research team using a commercial service. When PDF users finish the survey, they return the survey and data in PDF form, which are extracted and added to the database.

In the seventh step, the study analyzes the survey results and presents them in various formats. Text data, including the background information of the respondents, are first extracted to complete a summary study. The basic ideas of the text data are listed and summarized into several comments. Numerical and category data are combined and sorted after the text data. The study analyzes the means, standard deviation, and the ranking orders of the numerical and category data. The analysis is then presented in the formats of text, figures, and tables.

In the last step, the study develops findings and results. It synthesizes the findings based on existing literatures and the analysis based on the survey. It provides the current research status and professionals' preference while also providing a prediction on some potential research directions for the future.

3.2 Review of Literatures

To provide a better understanding of the subject research area, a comprehensive literature review is conducted. The review covers a wide range of literature sources and a full-scale of research topics related to the transportation emissions.

3.2.1 Sources of Literatures

The sources of literatures for the review include government documents, academic research papers and books, and emission related technical reports.

Government documents consist of all federal, state and local level emission and air quality reports, publications, memorandum and standards. The documents archive the regulation standards and provide official technical supports to emissions research. Reviewed documents include a number of legislative documents described in the Clean Air Act (CAA) (amended in 1990), emission inventory generating guidance from EPA or local agencies, emission testing procedures, and emission modeling guidance. Academic research papers consist of papers from major transportation, emission and air quality journals, papers presented at conference and seminars, emission related books and non-published research work. The reviewed papers and research work present important theories of transportation related emissions and the latest update of the emission research. Emission related technical reports consist of user's guide of equipments, technical manuals and new technology implementation reports. The reviewed reports summarize the commercial applications of emission related technologies and guidance in terms of implementation and problem solving.

The review also includes numerous literature sources of international emission research efforts. It includes European efforts to build measurement standard and models of the emissions, summarizes emission measurement and modeling development in China and other developing countries, and includes inter-modal emission studies, especially the emission research and development of international sea ports.

3.2.2 Topics of Literatures

The topics of the review of the study cover a wide range of study fields associated with the transportation emission research and findings. As discussed in Chapter 1, the research on transportation emissions is very broad, and it is impossible to cover all topics of this fast-evolving research area in this study. As such, this report strives to mainly cover the following topics.

The report first reviews the vehicle emission measurement technologies. In this part, the report introduces the traditional dynamometer testing, mandatory I/M programs, massive measured RSD, most popular PEMS, etc. Then the report reviews the vehicle emission modeling systems at macroscopic (regional), mesoscopic (segment or facility) and microscopic (individual) levels. It studies the models according to their development history and application areas. After completing the review of the vehicle emission measurement and modeling, the report presents its review on the emission reduction strategies. It lists the most effective reduction emissions strategies, such as vehicle design improvements, new energy technology, reducing or smoothing traffic, I/M programs, efficient transportation operations, and improving fuel economy. Besides the on-road emission related issues, the report also attempts to review aviation, marine, and inter-modal related emissions researches. It mostly focuses on the inter-modal international seaport emission issues. The report also expands the transportation related emissions to the relevant air quality research field. It investigates the most popular emission dispersion models and the connection between transportation related emissions and the air quality studies. In addition to all the technical issues of the transportation related emissions, the report goes through other important topics in this area, such as the greenhouse effect of emissions, emission project cost/benefit analysis, emission regulation, and legislative actions.

3.3 Design of Survey

As part of this study, a survey is designed and implemented on the behalf of the Department of Transportation Studiesat Texas Southern University (the TSU Survey). The objectives of the survey are to investigate the transportation emission professionals' personal opinions on existing transportation related emission research and future research directions.

3.3.1 Design of Survey Questionnaire

The design of the questionnaire (Appendix A) of the survey is divided into five sections with 30 questions in total. In the introduction section, the questionnaire introduces the study and the objectives of the survey. The introduction interprets instructions of the survey and provides contact information of the researchers of the study. The first part of the questionnaire is designed to investigate transportation emission measurement technologies and emission modeling system. In this part, professionals are asked to reveal their experiences and preference of the existing emission measurement technologies and modeling systems. They are then requested to provide their applications and purposes of using the technologies and modeling systems. They are also given the choice to evaluate the technologies and models that they used before. The second part of the questionnaire is designed to investigate professionals' experiences and opinions of other transportation related emission issues, such as emission reduction strategies, inter-modal emission research, emission dispersion, emission project cost/benefit analysis and emission regulation and legislative actions. In this part, professionals are requested to evaluate the effectiveness and mature level of the emission reduction strategies through a grading system. The survey investigates their opinions of other issues by providing objective choice. The third part of the questionnaire is designed to survey professionals' opinions of transportation related emission research gaps and projections of future development directions. In this part, more open-ended questions are provided to obtain free answers. For future development directions, professionals are asked to choose from the provided choices and present their ideas through the open-ended space. The fourth part of the questionnaire is designed to investigate professionals' background information for further analysis. In this part, professionals are requested to provide their working disciplines and their experience in the emission field. All of these questions are optional, and professionals can choose to answer based on their own preference.

As described in the sixth step of the general methodology, the survey is implemented by both web and email formats. Most professionals are able to answer questions through the website and the answers are automatically transferred to a database. For those who have difficulties in accessing the website, a PDF form of the survey is sent by email and the professionals can return the forms via e-mail as attachments.

3.3.2 Targets of the Survey

As described in the fifth step of the general methodology, the study develops a contact inventory of the survey targets based on their research publications and working disciplines. The survey targets are selected with a cross-disciplinary background of transportation, land use planning, and air quality fields. Basically, there are three types of professionals selected to be the survey targets in the study, including: professionals who work in the transportation discipline with experiences to analyze the relationship between transportation issues and emissions; professionals who work in the land use planning discipline with experiences to assess and reduce transportation related emissions using planning tools; and professionals who work as air quality experts with experiences to analyze transportation related air quality problems. Based on the selection criteria, the survey finally develops a sample size of 420 professionals.

According to the final selection, the 420 survey targets are from academia, governmental, and industrial fields worldwide. The selected professionals have emission related working or research experiences from one to 35 years.

3.3.3 Processing of Surveyed Data

After the survey is implemented, the data are automatically recorded and sorted to avoid recording errors that could occur by the traditional manual processing. For the website survey, the data are collected by the online service which automatically eliminates the re-submitted answers by blocking the duplicated log-on of the same explorer. The author downloads the results every other day to verify the effectiveness of the data. Empty forms are removed when detected. For the PDF version of the survey, the study imports the data automatically from the forms using the data collection functions from the software of Adobe Acrobat. Collected data are transferred to an excel worksheet format and added up together with the website survey results. After the combination, the whole dataset is transformed into a question based format, a text and choice answer based format, and a survey target group based format. Dataset is then analyzed according to its formats. For the question based format, figures and tables showing the results of each question are generated and presented. For the text and choice answer based format, a summary of the open-ended answers to each question is provided and a statement of the objective answers to each question is presented. For the survey target group based format, an analysis of the different ideas between respondents from academia and industrial fields is provided. The survey is kept open for two weeks and collects a total of 72 full responses which yields a 17% response rate in the end (Appendix B). For the survey target group, 41 out of the 72 respondents are from the academia fields with titles of Professor, Research Technician, and Graduate Research Assistant. Twenty professionals are from government agencies with titles of Air Quality Specialist, Planning Administrator, and Engineer. Eleven professionals are from private sectors with titles of Engineer, Analyst, and Scientist. For the convenience of the analysis, professionals from government agencies and private sectors are grouped together to represent practitioners in the emission fields.

CHAPTER 4: RESULTS AND DISCUSSION

In this chapter, the report strives to summarize and present the findings of the comprehensive reviews and the results from the survey. For the convenience of discussion, the chapter is divided into two parts: comprehensive reviews based on the literatures and survey results and analysis.

4.1 Comprehensive Reviews Based on Literatures

This section first summarizes the reviews of the vehicle emission measurement technologies, including dynamometer and driving cycle testing, I/M programs, RSD and PEMS. Reviews of the vehicle emission modeling systems are then presented, including the models at macroscopic, mesoscopic, and microscopic levels. After completing the review of the vehicle emission measurement and modeling, the report presents its review on the emission reduction strategies, such as vehicle design improvements, new energy technology, reducing or smoothing traffic, I/M programs, efficient transportation operations, and improving fuel economy. In addition to the on-road emission related issues, the report also attempts to summarize reviews of aviation, marine and inter-modal related emissions research. The report then expands the transportation related emissions to the relevant air quality research field. In addition to all the technical issues of the transportation related emissions, the report sums up other important topics in this area, such as green house effect of emissions, emission project cost/benefit analysis, emission regulation and legislative actions.

4.1.1 Review of Transportation Emission Measurement Technologies

Transportation emission measurement technology is a central piece of the entire transportation emission research. Technologies reviewed in this research are developed mainly based on the purpose to measure emissions of the on-road sources. The widely used measurement technologies include the dynamometer and driving cycle testing, I/M programs, RSD, and the PEMS.

The Dynamometer and Driving Cycle Testing. Dynamometer and driving cycle testing is the basic and most widely used emission measurement technology. The technology was first developed in mid-1960s with the original "LA4" (the early version of the Urban Dynamometer Driving Schedule) driving cycle and some refinements of the dynamometer technology (OMS & OAR, 1993). Based on the testing objectives, the technology is categorized as chassis dynamometer testing and engine dynamometer testing. Applications of the technology provided emission data for the developments of numerous emission models, including EPA's MOBILE series model (An, Barth, Norbeck, & Ross, 1997; EPA, 2004a; North, Noland, Ochieng, & Polak, 2006). Dynamometer technology was adopted by counties worldwide in terms of generating emission inventories (Corvalan & Vargas, 2003; Fukuda et al., 2007). It was used to test various emission chemicals from different sources, including newly developed hybrid technologies (Zhu et al., 2004; Oh, 2005). It was implemented to help calibrate emission data measured by PEMS (North et al., 2006). At present, the application of the technology is closely associated with a variety of driving cycles. Researchers around the world developed driving cycles that could represent their specific driving pattern characteristics, and some of these cycles have been adopted as emission certification and emission regulation compliance tests. The widely used driving cycles include the United States Federal Test Procedure (FTP) 75, United States Highway Fuel Economy Driving Schedule (HWFET), the New York City Cycle (NYCC), EPA's Heavy Duty Urban Dynamometer Driving Schedule, European ECE Driving Cycle, Extra Urban Driving Cycle (EUDC), and the Japanese 10-15 Mode Cycle (EPA, 2007a; Samuel et al., 2002; Preschern & Engeljehringer, 2001; Ecopoint, Inc., 2007). Although dynamometer and driving cycle-based emission measurements were developed 3 decades ago and were widely accepted, the technology has some limitations which constrain its applications. Because of the requirements of the costly dynamometer equipment and long time occupation of the testing vehicles, the tests are usually too expensive to conduct and repeat, especially for those unbeneficial research institutes. Moreover, since the data were derived from laboratory conditions, they were often questioned for their capability to reflect the reality and the data accuracy.

The Vehicle Inspection and Maintenance Programs. I/M Programs are used as an emission measurement technology for their function as an inspection program. I/M program technology was developed with the force of EPA for the responsibility of the CAA in 1970s. As CAA was amended in 1990, EPA set guidelines for states to follow in designing and running I/M programs. It distinguished basic and enhanced I/M programs according to zonal air quality. These guidelines also set the performance of Onboard Diagnostic (OBD) system checks as part of the requirements. Emission measurement procedure is based on the dynamometer measurement technology. It forces the in-use vehicles to have a basic emission test using an EPA's standard chassis dynamometer schedule with 240 seconds (IM240) and use RSD or road-side pullover tests as enhancements to the basic requirements. EPA also recognized California's Acceleration Simulation Mode (ASM) as an acceptable alternative to IM240 for meeting the enhanced performance standard since 1995 and accepted flexible evaluation methodology besides IM240 since 1998 (OTAQ, 2004a). In addition to IM240 and ASM, there is a supplemental testing recommended to ozone non-attainment areas, such as idle testing and FTP testing. In its Regulatory Announcement (OTAQ, 2004c), EPA proposed to establish the implementation deadline for new I/M programs required under the eight-hour standard as four years after the effective date of classification under the eight-hour standard. It proposed to change the current, fixed deadline for beginning program evaluation testing to the more relative deadline of "no later than one year after the program starts up." It also proposed to establish the submission deadline for new I/M SIPs required under the eight-hour standard. Submission deadline dates would be set for one-year after the effective date of the final action on the current proposal. Application of the I/M measurement was mostly used as a rich data source to reveal relationships between vehicular emissions and characteristics (Beydoun & Guldmann, 2006; Bin, 2003). One shortcoming of this measurement technology is the high cost to the entire society. It was also being questioned for its data accuracy because of its chassis dynamometer base and the limitations by acquiring data from OBD II programs only.

The Remote Sensing Device. The Remote Sensing Device (RSD) is used as an emission measurement technology for its function of measuring emissions without stopping the vehicles. The RSD was first developed at the University of Denver in the late 1980s and commercialized in 1991 by the Environmental Systems Products, Inc (ESP)'s predecessor remote sensing organization, Remote Sensing Technologies, Inc. (RSTi). In 1996, EPA formally recognized remote sensing screening applications and released its first RSD "guidance" on high emitter identification (Vescio, 2002). The emission measurement procedure is to use the Infrared (IR)/Ultraviolet (UV) absorption principle to test absorption rate when a vehicle passes through a calibrated infrared or ultra violate radiation beam. Absorption data are then calculated using combustion equations to determine the emissions concentrations of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxide (NO), and carbon dioxide (CO2) in the diluted exhaust (Virginia DOEQ, 2003). RSD also employs a freeze-frame video camera and equipment to digitize an image of the license plate number to identify vehicles' fleet information (OTAQ, 2004b; OMS, 1993). Applications of this measurement technology focus on evaluating and enhancing the effectiveness of I/M programs, improving fleet documentation of I/M program, developing and evaluating emission models and inventories and synthesizing the traffic and emission models (Bishop & Stedman, 1996; Eastern Research Group, 2004; Lawson, 1993; Stedman, Bishop, & Slott, 1998; NYDOEC, 2003; Swayne, 1999; Wenzel & Sawyer, 1998; Singer & Harley, 1996; Yu, Lede & Godazi, 1998; Yu, 1998). Remote sensing technology was adopted for its on-road emission measurement advantages and its capability to generate a rich data source with relatively low cost. A major negative side of this technology is that it only measures the emission concentrations.

The Portable Emission Monitoring System. The PEMS is an emission measurement system which keeps gaining acceptance and attentions. This measurement technology was developed with the lead of EPA in the late 1990s. EPA developed the first (ROVER) and second (SPOT) generation of PEMS and also licensed its technology to equipment manufacturers to encourage and support private industry in the development and refinement of the equipment. The measurement procedure is to record the emission with on-board emission analytical tools while the vehicle is operating in real-world conditions. Popular commercial PEMS products include: OEM Montana system which was verified by EPA's The Environmental Technology Verification (ETV) Program in 2003, RAVEM system, SemtechD system, etc (Myers, Kelly, Dindal, Willenberg, & Riggs, 2003; Weaver & Balam-Almanza, 2001; Weaver & Petty, 2004; Dearth et al., 2005). In the application field, the PEMS can be used together with traditional dynamometer tests as a supplementary source of emission measurements or as an independent emission measurement tool to collect transportation related emissions of the in use fleet while operating (North et al., 2006; Doraiswamy, Davis, Miller, Lam, & Bubbosh, 2006; Frey, Rouphail, & Zhai, 2006; Krimmer & Venigalla, 2006; Schipper et al., 2006). To test new technology related transportation emissions such as emissions from hybrid urban buses, extremely low-emitting vehicles or dump trucks fueled with biodiesel is another important application of the PEMS measurement (Vikara & Holmen, 2006; Barth, Collins, Scora, Davis, & Norbeck, 2006; Frey & Kim, 2006). These applications also show that the PEMS are very capable of being refined or even being self-resembled to fit the emission measurement needs (Barth et al., 2006; Jackson, Qu, Holmén, & Aultman-Hall, 2006). As a newly developed system, the PEMSs are somehow questioned for data accuracy and capability to measure massive fleet of vehicles, but the criticism did not stop the increasing interests, attention and continued improvement of this technology.

Findings from the Review. Based on the review above, the transportation emission measurement system combines both laboratory and field test methods. It is able to serve the need to measure emissions from a general fleet and individual objectives. The measurement system is experiencing a refinement process from laboratory testing to real-world data collection.

4.1.2 Review of Emission Modeling System

The current emission modeling system is composed of a number of models which can estimate and predict transportation emissions at all macroscopic (regional), mesoscopic (segment or facility), and microscopic (individual) levels. The travel-based and fuel-based models are at a macroscopic level, while the instantaneous and integrated emission-traffic models are at a microscopic or mesoscopic level.

Travel-based Emission Models. Travel-based emission models combine the calculated emission factors in certain regions with a region's travel data to generate emission inventories for emission estimations. The representative travel-based emission model is the MOBILE emission factor model developed by EPA. Inventories calculated by MOBILE are used to make decisions about air pollution policy and programs at the local, state, and national levels. The inventories are also used to match the federal Clean Air Act's State Implementation Plan (SIP), and to match the transportation conformity requirements and the National Environmental Protection Act (NEPA) requirements (EPA, 2004a). The latest version of the MOBILE, MOBILE 6.2, is now the most widely used emission factor model which is adopted all over the world (Qiao, Wang, & Yu, 2007). Although the MOBILE has been used and updated for nearly three decades, it is criticized for being constrained by its model frame which limits the use and refinement for multi-level emission estimation. To address this problem, EPA started to develop a new generation emission model which is widely known as MOVES (EPA, 2004c). MOVES started to use the PEMS measurement technology to collect real-world emission data as part of its data source to develop emission factors which can be updated upon the vehicle operation situation. MOVES was expected to be capable of estimating emissions at all macroscopic, microscopic and mecroscopic levels in the future. EMFAC, a model developed by CARB, is another reprehensive travel-based model with similar structure and functions as MOBILE, but is used to enhance the compliance of stricter emissions standards in California. The newly developed travel-based International Vehicle Emissions (IVE) model is commented as an improved estimation tool of mobile source emissions for applications in developing countries (Davis, Lents, Osses, & Barth, 2005).

Fuel-based Models. Fuel-based models utilize fuel use data that are available from tax records as the traffic database to estimate emissions. The fuel-based model may use traditional dynamometer emission measurement or other measurement technologies; for instance, RSD to calculate emission factors per unit of fuel used (EEA, 2000; Pokharel, Bishop, & Stedman, 2002). When combined, the emission rate and fuel use data can generate a fuel based emission inventory. One of the widely used fuel-based models, the Computer Programme to Calculate Emissions from Road Transport (COPERT), was developed by European Environment Agency (EEA) in 1985 (EEA, 2000). It has a similar structure as MOBILE, but utilized the regional fuel sales data as traffic data alternative. The model and the fuel-based method were found suitable to the areas lack of surveyed traffic data (Zachariadis & Samaras, 1999).

Modal and Instantaneous Emission Models. Modal and instantaneous emission models predict second-by-second tailpipe emissions as a function of the vehicle's operating mode. The most representative and widely accepted modal and instantaneous emission model is the Comprehensive Modal Emissions Model (CMEM) developed at the University of California, Riverside (An et al., 1997). After the initial development of the model, researchers kept on validating the model and making further development to enable the model to estimate more emission sources, for instance, the heavy duty diesel vehicle emissions (Barth, Malcolm, Younglove, & Hill, 2001; Barth, Scora, & Younglove, 2004). The model was adopted in El Paso, Texas, in a case study (Farnsworth, 2001). Another example of the instantaneous emission models is the Virginia Tech Microscopic Energy and Emission Model (VT-Micro) which was developed using chassis dynamometer data (Rakha, Ahn, & Trani, 2004). The logic of this model and application had been implanted in the microscopic INTEGRATION model for fuel consumption and emission calculation (Rakha & Ahn, 2004).

Integrated Models. Besides the independent modal and instantaneous emission models, some micro emission estimation logic and method was integrated with microscopic traffic models to analyze the traffic operation impact on emissions. Popular integrated models include INTEGRATION, TRANSIMS and VISSIM. INTEGRATION was initially developed in 1983 and evolved into a microscopic model in 1995. The microscopic energy and emission model was developed as an enhancement to the original model (Rakha, 2007). The model integrated the logic of the VT-Micro model as its emission module. It can also model emission dispersion using a simplified plume dispersion model (M. Van Aerde & Assoc., 2005). The model was used to analyze operational characteristics, such as the roadway grades impacts on energy and fuel consumption (Park & Rakha, 2006). The Transportation Analysis and Simulation System (TRANSIMS) is an activity-based travel demand forecasting model developed at the Los Alamos National Laboratory (LANL). It combined its instantaneous traffic forecasting data with emission characteristics to estimate individual vehicles or regional emissions. The model was applied to estimate emissions for case studies in New Mexico and Houston, TX (Williams, 1999; Zietsman & Rilett, 2001). VISSIM is a microscopic, time step and behavior based simulation model developed to model urban traffic and public transit operations (PTV, 2005). The model has an optional module of emissions estimation. The module can estimate instantaneous fuel consumption and tailpipe emissions based on the simulation stages. It is also available to estimate the evaporative emissions and accumulative emissions via a time interval.

Findings from the Review. Based on the review, the model system covers a regional, segment/ facility and individual levels emission modeling. EPA's new generation model will be able to serve the need of all levels. It will keep the status as a reference to emission modeling research and practice. The research works have a trend to combine the emission models with transportation and simulation models.

4.1.3 Review of Existing Emission Reduction Strategies

The emission measurement and modeling were to provide an input tool to the policy making process. The air quality management policy serves the objective of controlling and reducing emissions, therefore, the emission related actions, including the measurement and modeling system, all serve a final purpose to reduce emissions. Since the 1970s, with the force of CAA, numerous emission reduction strategies have been developed and implemented to control and reduce transportation related emissions.

Vehicle Design Improvements. Among emission reduction strategies, vehicle design improvements were the basic and most effective ways to control emissions. The improvements of vehicle design include engine/fuel system improvements, catalyst converter refinement and aerodynamic system improvements. The engine/fuel system control emissions by optimizing air recycling and fuel/air ratio control systems. The catalytic converters control emissions by oxidizing the products of incomplete combustion. Therefore, the process in some case can convert the toxic emissions into non-toxic chemicals with the control of the stoichiometric point, for instance, CO to CO_2. The aerodynamic system improvements increase the energy efficiency by optimizing the mechanic operation of vehicles.

New Energy Technology. Besides refinement of vehicle systems, the new energy technology is another important strategy to reduce transportation emissions. The energy technologies include fuel alternative, renewable fuel, and clean energy. Recently, bio-fuels were demonstrated to be able to reduce criteria and greenhouse gas emissions (Griffith, 2007; McNally, 2006). Hybrid-electric propulsion systems are experiencing increased commercialization as a result of their improved fuel economy and reduced emissions.

Reducing or Smoothing Traffic. Reducing or smoothing traffic also plays an important role in terms of reducing transportation related emissions. Land use planning and transportation system planning, traffic control strategies, and Intelligent Transportation Systems (ITS) applications are considered as efficient ways to smooth traffic, and in the same way, to reduce emissions (Hao, Hu, & Fu, 2006; Kear & Niemeier, 2004; Mostashari, Sussman, & Connors, 2004).

I/M programs. I/M programs were created to ensure that motor vehicle emission-control systems operate properly throughout the life-time of the vehicle. The programs reduce emissions by identifying high emitters and requiring them to be repaired or removed from the fleet. The benefits I/M programs in the emission reduction are documented in state I/M program reports (Missouri I/M Group, 2005).

Efficient Transportation Operations. Efficient transportation operations were proved to be effective emission reduction strategies as well. The potential operational improvements which may have positive impacts on emission reductions include traffic system optimization, ramp metering technology, and ITS technology. The operational strategies are usually evaluated at a microscopic level for certain traffic improvements projects (Venigalla & Krimmer, 2006).

Improving Fuel Economy. Improving fuel economy was considered as a contribution to reduce transportation related emissions, especially in term of reducing GHG emissions. To encourage the fuel economy production, the federal government administers three programs to provide information to consumers about fuel economy. Corporate Average Fuel Economy (CAFE) is the required average fuel economy for a vehicle manufacturer's entire fleet of passenger cars and light trucks for each model year. EPA reports the CAFE results for each manufacturer to National Highway Traffic and Safety Administration (NHTSA) annually and NHTSA determines if the manufacturers comply with the CAFE standards and assesses penalties as required. Every year since 2000, EPA publishes Green Vehicle Guide to help consumers identify the cleanestand most efficient vehicle that meets their needs. The Gas Guzzler Tax is also imposed on manufacturers of new model year cars that fail to meet the minimum fuel economy level of 22.5 mpg to discourage the production and purchase of fuel inefficient vehicles (EPA, 2004b).

Findings from the Review. Based on the review above, the emission reduction activities are required by laws and are administrated by federal and state governments. The reduction activities involve efforts of governments, manufacturers, and customers. The actions make credits in terms of reducing criteria pollutants and GHG emissions.

4.1.4 Review of Other Transportation Related Emission Issues

Although on-road mobile-source emission is the dominant source of transportation related emissions, its measurement, modeling, and reduction are not the only issues of the research related to transportation emissions. There are other relevant topics such as emissions from other sources, GHG emissions and control, emission dispersion, emission legislation/regulation, emission reduction project, cost/benefit analysis, etc. The following are some of examples of other issues.

Non-road Emission Sources. In addition to the on-road mobile source emissions, other emission sources such as marine, aviation, railway, and off-road handling equipments are considered to be compositions of the transportation related emissions. For marine source emissions, EPA provides commercial marine emissions inventory and emission control guidance for marine diesel engines (Corbett & Fischbeck, 1998; OAR, 1999). For non-road engines, EPA provides exhaust and evaporative emission factors for non-road emission modeling. For railway source, EPA published a regulatory support document for locomotive emission standards (OTAQ, 2005b; OTAQ, 2005c; OMS, 1998). For aviation source, EPA published a regulatory support document to control air pollution from aircraft and aircraft Engines and provided emission standards and test procedures for the aircraft and aircraft engines (EPA, 1997; OTAQ, 2005a). Other than US EPA's efforts of regulating, measuring and reducing emissions from transportation modes, research on modal emissions were conducted all over the world (Qiao et al., 2007). Currently, modal emissions research shows a tendency to investigate inter-modal emissions. As multi-modal emission research areas which merge marine, rail, truck, and non-road equipments emissions, the marine ports are gaining more attention nowadays. Research of the port emissions mainly focused on analyzing and regulating emissions of all modes involved, and the research had spread worldwide besides the regional analysis in the U. S. (Dykman, 1995; Rizk, Jabry, & Benabdennbi, 2001; Watanabe, 2004).

Transportation Emission Dispersion. The transportation related emission is important because it has significant negative impacts on living creatures. Therefore, the research that focuses on transportation emission dispersion and its impacts on air quality is considered as another important issue. Preferred and recommended models include AERMOD, CALPUFF, BLP, CALINE series, CTDMPLUS and OCD. The CALINE series are the most widely used emission dispersion models (Coe et al., 1998). In addition to the preferred and recommended models, there are alternative models such as ADAM and AFTOX, screening models such as SLAB and AERSCREEN, and photochemical models such as Models-3/CMAQ and CAMx. The accuracy of the dispersion model relies on the accuracy of the emission data. For instance, the Sparse Matrix Operator Kernel Emissions Model (SMOKE) is used as preprocessor for the CMAQ dispersion model. Then the accuracy of the dispersion will be determined by both SMOKE and CMAQ (Qiu, Lepage, & Altena, 2001).

Greenhouse Effect. Another negative impact of transportation related emissions is its significant contribution to the greenhouse effect. Transportation is the fastest-growing source of U.S. GHGs and the largest end-use source of CO2. To reduce transportation GHG emissions and save fuel, EPA promotes strategies Clean Automotive Technology research and a range of voluntary programs to encourage efficient freight transport and alternatives to single occupancy travel. EPA also developed the Green Vehicle Guide which helps consumers do their part to reduce greenhouse gas emissions by providing information to help in picking the cleanest, most fuel-efficient vehicle that meets their needs (EPA,2003).

The Legislative and Regulatory Action. The legislative and regulatory action towards transportation related emissions defined the research area and directions. The US DOT-FHWA did a summary of environmental legislation affecting transportation in 1998. This summary listed three air quality related legislative references besides the general environmental statutes. They are the Clean Air Act-Conformity, Clean Air Act –Sanctions, and Congestion Mitigation & Air Quality Improvement (CMAQ) (FHWA, 2007). In addition to the legislative references, regulatory emission standards were assigned to emission resources and to national, state, and regional levels. All emission research should comply with the laws and regulation requirements.

The Cost/benefit Efficiency Analysis. The cost/benefit efficiency analysis is necessary in evaluating emission measurement, modeling, or reduction projects. There are some arguments that sometimes, the emission reduction actions may cost more than the emission reduction benefits. For instance, I/M programs are usually questioned for their high cost, but limited reduction benefits. However, the cost-benefit analysis was ignored in many emission research projects.

Findings from the Review. Based on the review above, the transportation emissions cover a wide range of related issues. The research and practice territory of this topic keeps spreading. It is a multi-task to cover all inter-modal emission controlling, impacts on air quality and environment, regulatory action, and economy impacts analysis. Transportation emission research is becoming a cross-disciplinary subject which combines transportation, planning, chemistry, and environmental studies.

4.2 Survey Results and Analysis

In this part, the report summarizes and presents the results and analysis of the survey. It first presents the evaluation and comments of the emission measurement technologies, including professionals' current and future preference of the technologies, the purpose of emission measurement, and evaluation of the entire emission measurement system. The report then summarizes the comments and evaluation of emission modeling system, including professionals' preference on the models, evaluation of each model, model development experiences, and evaluation of the entire modeling system. The report, then, sums up the evaluation and preference of emission reduction strategies, including the evaluation of the mature level and effectiveness. The report also attempts to summarize professionals' experiences in the emission dispersion modeling and analysis, emission related cost/benefit analysis, and legislative activities. Finally, the report forecasts the potential research directions based on professionals' preference shown in the survey.

4.2.1 Evaluation and Comments of Emission measurement Technologies

To reveal transportation emission professionals' evaluation and comments on the emission measurement technologies, the TSU Survey investigated the usage, evaluation, and future preference of each existing measurement technology. It also surveyed the respondents' level of dissatisfaction and expectation of the entire system.

For the usage of each technology, the percentages of respondents who indicated they used dynamometer and driving cycle testing, RSD, PEMS, and I/M program technologies are 33.93%, 41.07% 73.21%, and 21.43%, respectively, as shown in Figure 1. There were 17.86% of respondents who also provided other existing emission measurement technologies such as tunnel studies, which collect emission data in a tunnel, inverse air quality modeling, which uses measured air quality data to trace back emissions, chase-vehicle measurements, which collect emission chemicals when chasing a vehicle on-road, and so on.

For the future preference of the technologies, the percentages of respondents who indicated they would choose dynamometer and driving cycle testing, RSD, PEMS, I/M program, and other technologies were 43.48%, 58.70%, 86.96%, 8.70% and 12.24%, respectively, as shown in Figure 1. Compared to the percentage for usage of the technologies, the future preference is slightly different. First, the percentages of respondents who chose dynamometer and driving cycle testing, RSD, and PEMS increased by 9.5%, 17.6% and 14.6%. Especially for the PEMS technology, the significant high preference indicated that it would be the dominating emission measurement technology in the future. The latest research already showed a similar tendency. For example, as reviewed recently, seven out of 17 academic papers from the 2006 Air Quality Series of the Transportation Research Record (TRR) adopted PEMS as the emission measurement technology for the projects. Or in another way, among eight TRR papers which conducted emission measurement as part of the projects, 87.5% or seven of them were accomplished with PEMS technology.

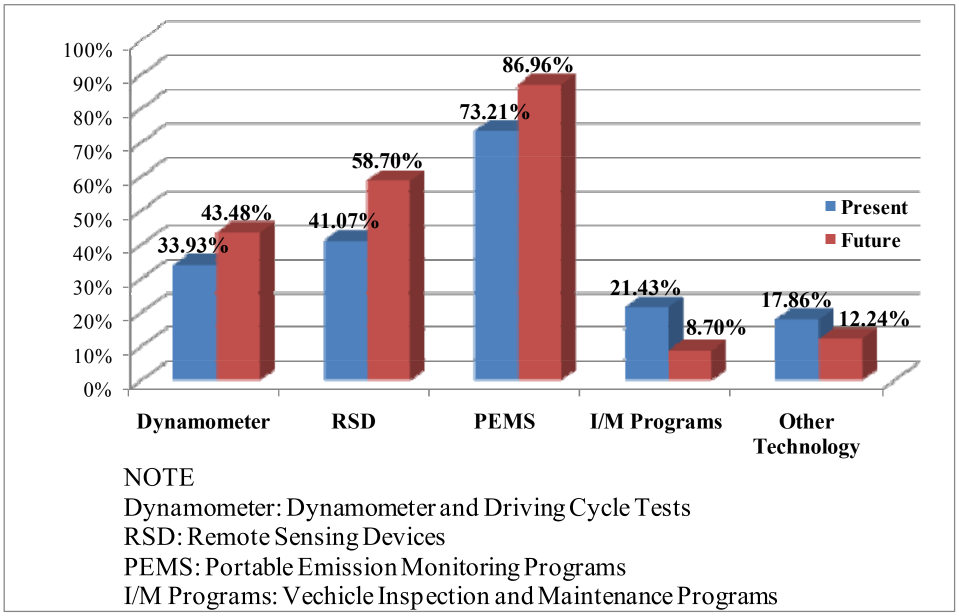

Figure 1 Emission Measurement Technologies-Present and Future Preference

To examine whether there is a difference between the technology usage by researchers and all respondents, researchers' preference of present and future emission measurement technologies is presented separately. As shown in Figure 2, researchers' choice is similar to that of all the respondents: 1) Present usage of the technologies concentrates on PEMS (researchers' 86.7% compared to all respondents' 73.21%), RSD (42.86% compared to 41.07%) and Dynamometer tests (31.43% compared to 33.93%). 2) Future preference of the technologies will still focus on PEMS (researchers' 90.63% compared to all respondents' 86.96%), RSD (53.13% compared to 58.70%), and Dynamometer tests (46.88% compared to 43.48%). 3) The Future usage of the I/M Programs as a measurement technology will reduce, based on both researchers and all respondents' choice: researchers' 17.14% down to 5.25% compared to all respondents' 21.43% down to 8.70%. Besides the similar choice, comparing the preference of all respondents, researchers' choice of present and future technologies is more concentrated on PEMS. There were 86.71% researchers who indicated they used PEMS before, while 73.21% of all respondents claimed they used PEMS. There were 90.63% researchers and 86.96% of all respondents who showed they will use PEMS in the future.

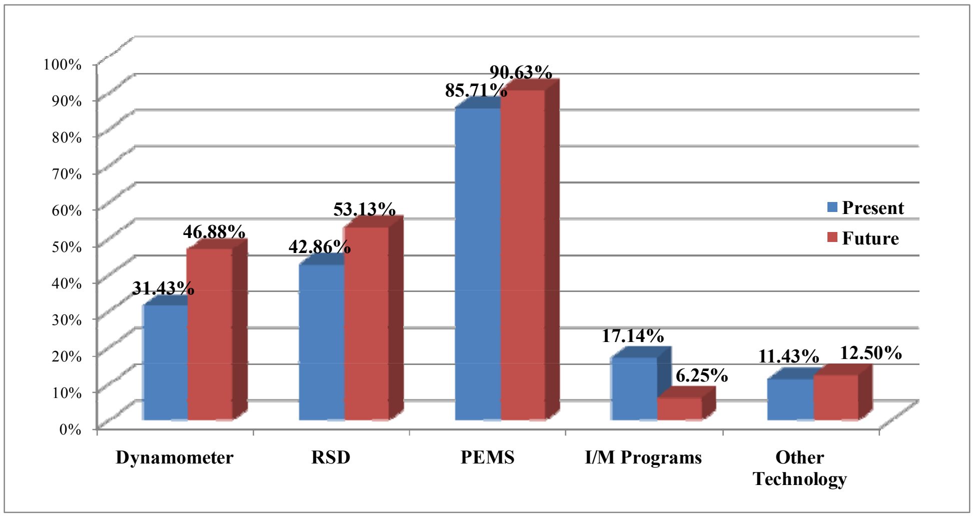

Figure 2 Researchers' Choice of Emission Measurement Technologies

Figure 3 illustrates the evaluation of each technology, in which the dynamometer beats all other technology with a 3.87 overall ranking. Except for its cost/benefit efficiency (3.14, ranking the 4th) and equipment easy to handle (2.87, ranking the last), the dynamometer technology was evaluated as the best for data reliability and second for widely used (slightly less than I/M programs). The PEMS was ranked the second (3.57) overall. The surveyed professionals gave the PEMS positive evaluation in almost every aspect. It was given scores over 3.5 for all data reliability (3.52), cost/benefit efficiency (3.55), and easy to handle (3.66) parameters. For the evaluation of the technology widely used, the I/M program was ranked the first because it is mandatory in many states.

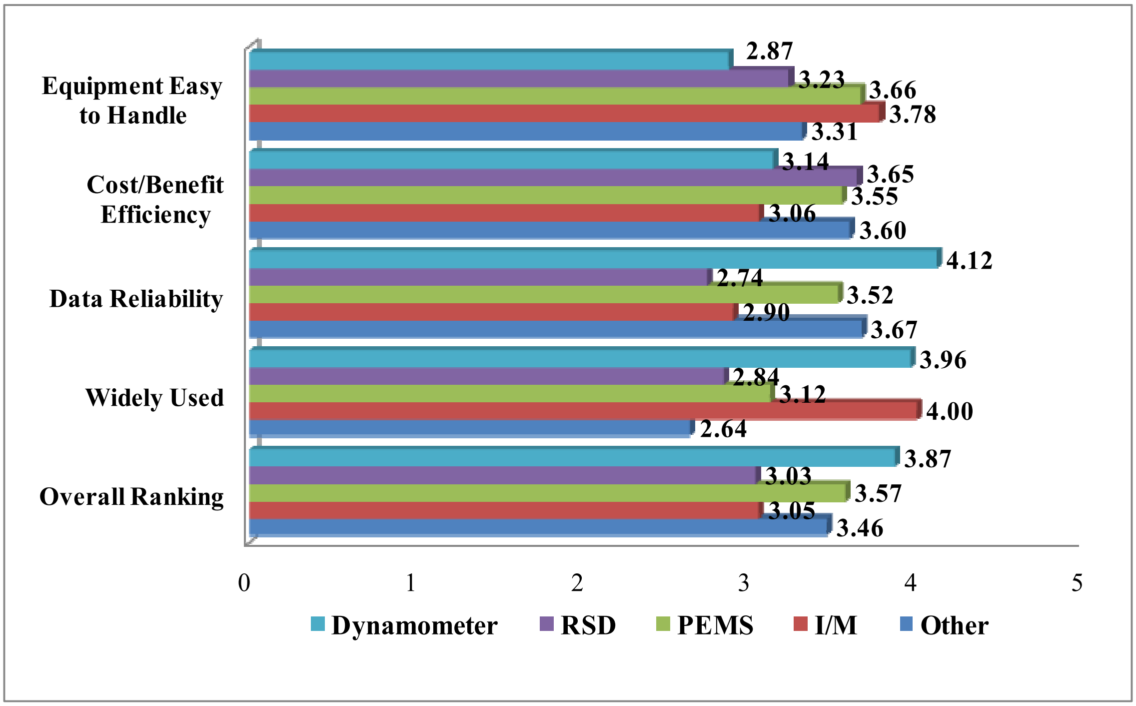

Figure 3 Evaluation of Emission Measurement Technologies

Researchers' evaluation of the technologies is also presented separately to identify whether it is different from that of the entire survey sample. As illustrated in Figure 4, researchers ranked the Dynamometer tests as the first for its data reliability (4.2, all respondents' grade 4.12), I/M Programs as the first for its most widely used (4.33, all respondents' grade 4.00), and RSD as the first for its cost/benefit efficiency (3.68, all respondents' grade 3.65). These results are the same as the evaluation from all respondents, although the grades are slightly different.

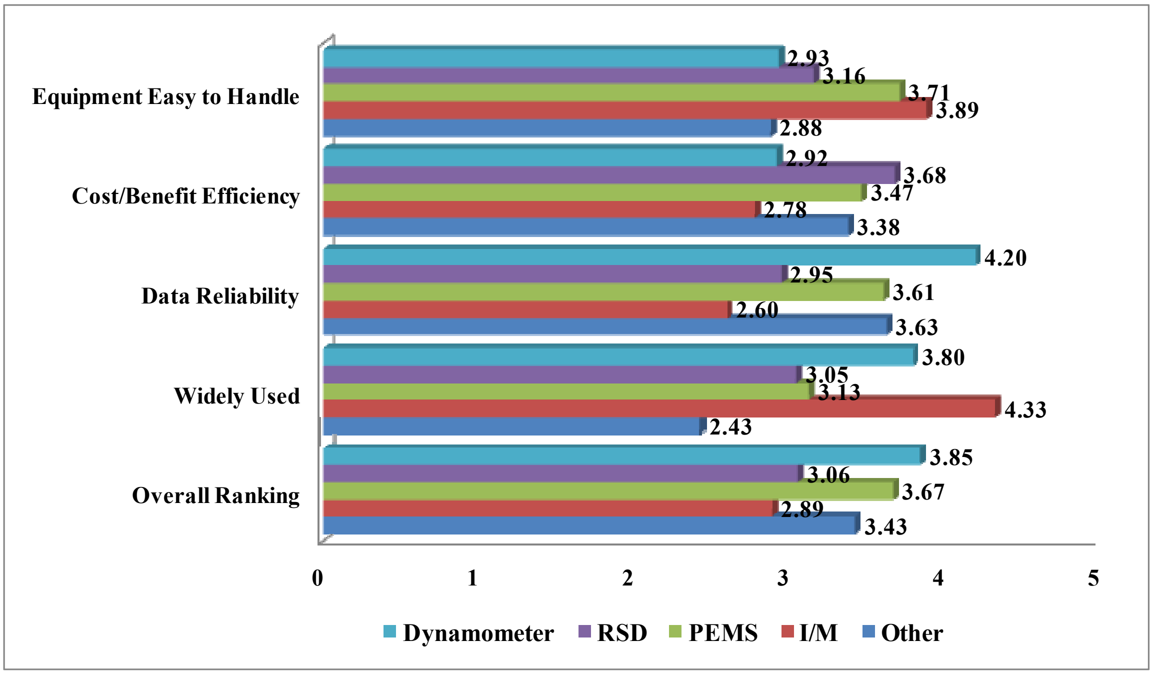

Figure 4 Researchers' Evaluation of Measurement Technologies

Regarding the purposes of emission measurements, the TSU Survey showed that 75.41% of the respondents indicated they would use the emission data to analyze the impacts of transportation operation on emissions, 55.74% respondents used or will use the emission data to develop new emission models, while 36.07% respondents related the data with emission model calibration, and 52.46% respondents collected emission data to analyze impacts of the new emission reducing technologies, as shown in Figure 5. Other purposes mentioned by respondents include using emission data to assess I/M standards, to identify high emitters, to conduct spot check to compare with the idle emissions standards and to develop driving cycles.

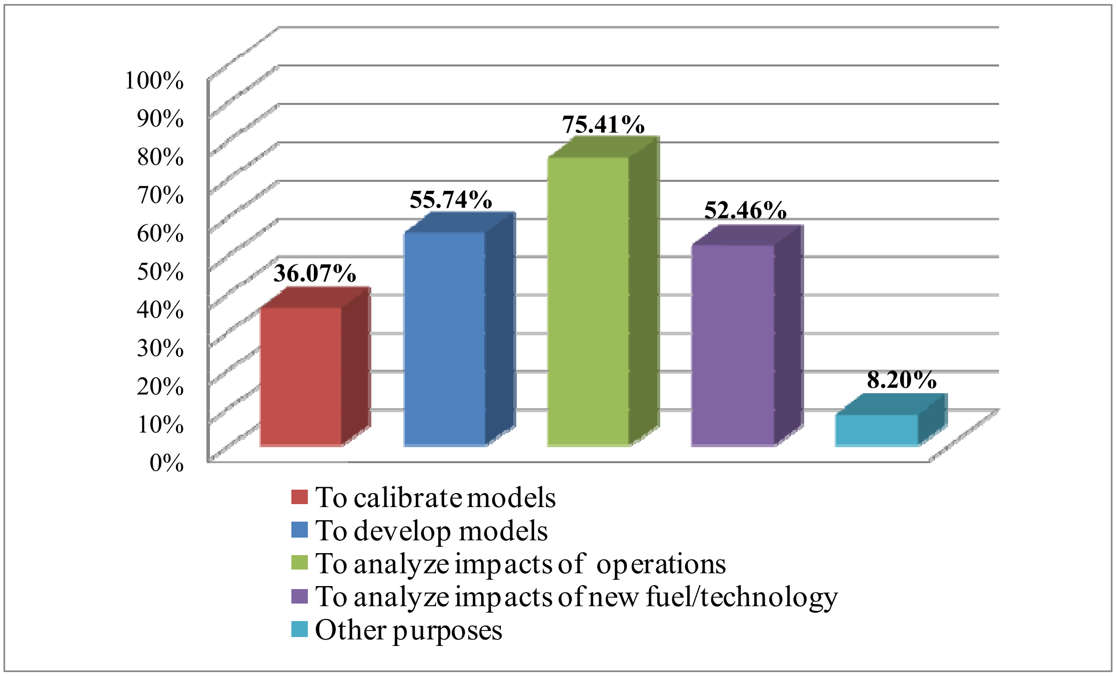

Figure 5 Main Purposes of Emission Measurement

For the evaluation of the entire emission measurement system, 58.49% respondents thought it is possible to find appropriate data collection technology most of the time, while 24.53% felt that it is hard to find an appropriate data collection technology most of the time. For those respondents who argued that there are specific requirements which cannot be met by using the existing measurement systems, they mostly doubted the data accuracy, questioned the device availability, and mentioned the high measurement costs.

Although the survey questionnaire was distributed worldwide and received responses from both research and practice disciplines, there is no respondent who can represent the metropolitan planning organizations (MPO). In order to fill the gap, the study conducted an email interview with the air quality planners from The Houston-Galveston Area Council (HGAC) which is at the MPO level for the Gulf Coast Planning region of Texas. According to the response from the air quality planners, HGAC does not collect field emission data by its own. It is in charge of modeling on-road mobile source emissions. The necessary emission and travel data come from Texas Department of Transportation (TxDOT), the EPA, Texas Commission of Environmental Quality (TCEQ), and H-GAC's transportation demand modelers.

4.2.2 Comments and Evaluation of Emission Modeling System

To reveal transportation emission professionals' evaluation and comments on the emission modeling system, the TSU Survey investigated the usage, evaluation, and future preference of each popular emission models. It also surveyed the respondents' experiences of developing an emission model. The respondents' level of dissatisfaction and expectation of the entire system were also analyzed.

As a result for the usage of the existing models, the percentages of respondents who indicated that they used the travel-based models, fuel-based models, modal and instantaneous models, and integration of transportation and emission models were 95.08%, 19.67%, 45.90% and 54.10%, respectively, as shown in Figure 6. This result shows that as traditional modeling systems, the travel-based macroscopic models were most widely accepted and applied. The newly developed microscopic models also gained significant attention considering their short history.

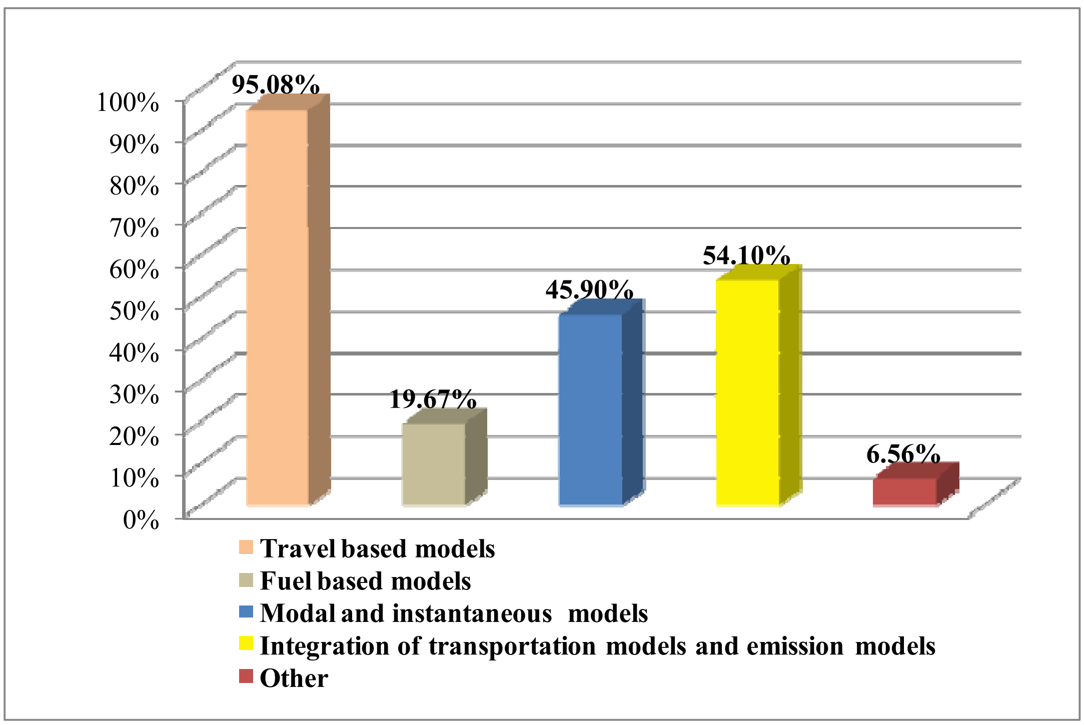

Figure 6 Usage of Existing Models

In Figure 7, the separately presented researchers' usage of existing models shows that all categories of emission models are more widely adopted by researchers. There are 97.44% researchers who indicated they used the travel based emission models (95.08% for all respondents), 25.64% researchers showed they utilized the fuel based emission models (19.67% for all respondents), 56.41% researchers claimed they tried the modal and instantaneous emission models (45.90% for all respondents) and 64.10% researchers showed they took the integrated models (54.10% for all respondents).

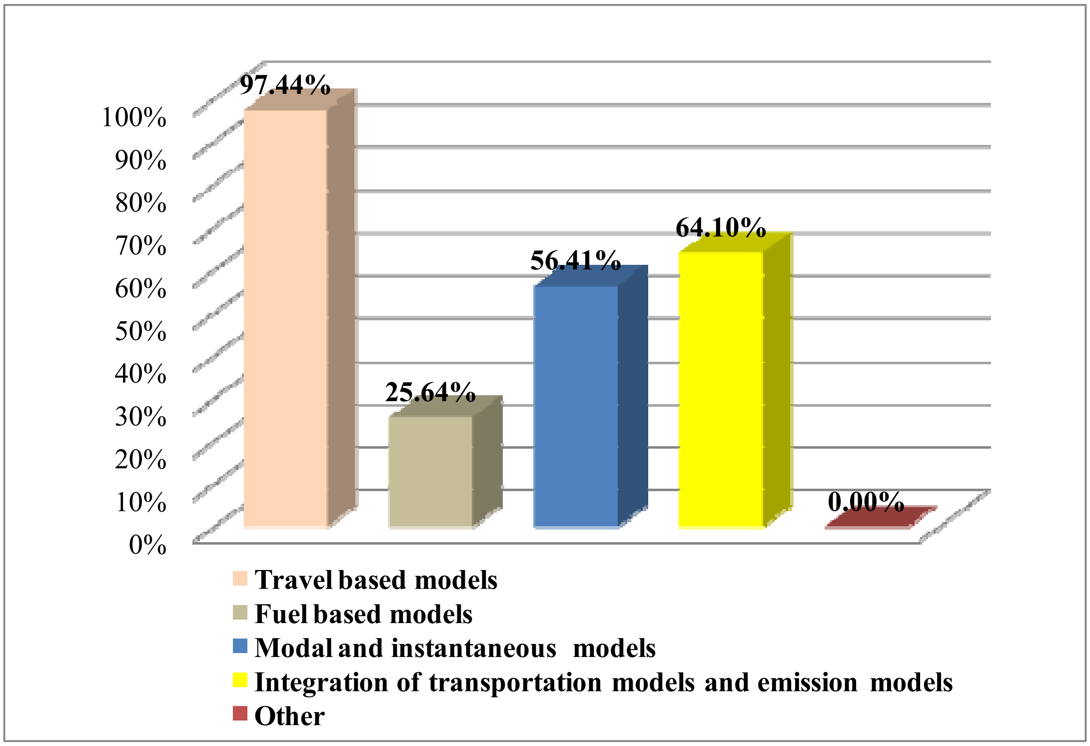

Figure 7 Researchers' Usage of Existing Models

Figure 8 illustrates the evaluation of the models, in which MOBILE was ranked the first (4.63) for the widely used category. The INTEGRATION was given the highest evaluation data accuracy (3.55). COPERT beats other models in the aspect of easy implementation (3.90). IVE was ranked as first for user friendliness (4.18). For the overall ranking, the VISSIM (3.39) and IVE (3.40) were given the highest scores. As noticed, the most popular MOBLE and CMEM were not evaluated to be better models in the entire system. This phenomenon implies that although these models were and will be selected for emission estimation, they still have shortcomings and flaws. There is a need of a new generation of models which can provide better service and will be supported by the government.

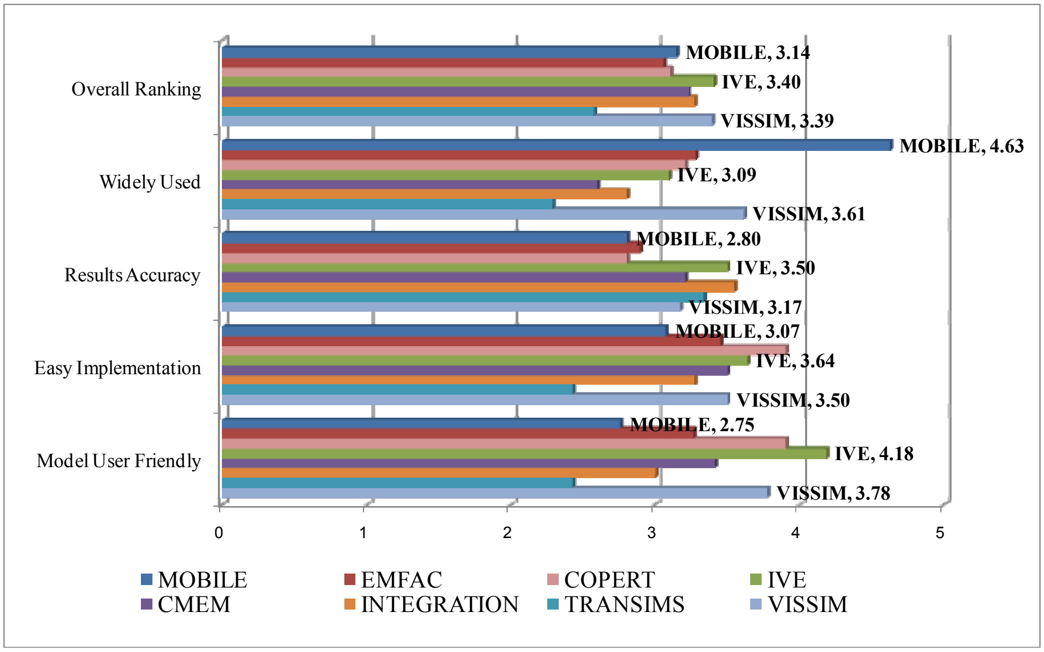

Figure 8 Evaluation of Emission Models

Figure 9 shows researchers' evaluation of the models. MOBILE was also ranked the first (4.54, comparing to all respondents' evaluation 4.63) for the widely used category. IVE was also ranked as first for user friendliness (4.22, comparing to all respondents' evaluation 4.18). For the overall ranking, the VISSIM (3.44, comparing to all respondents' evaluation 3.39) were given the highest scores. The results are identical to the evaluation from all respondents, although the grades are slightly different.

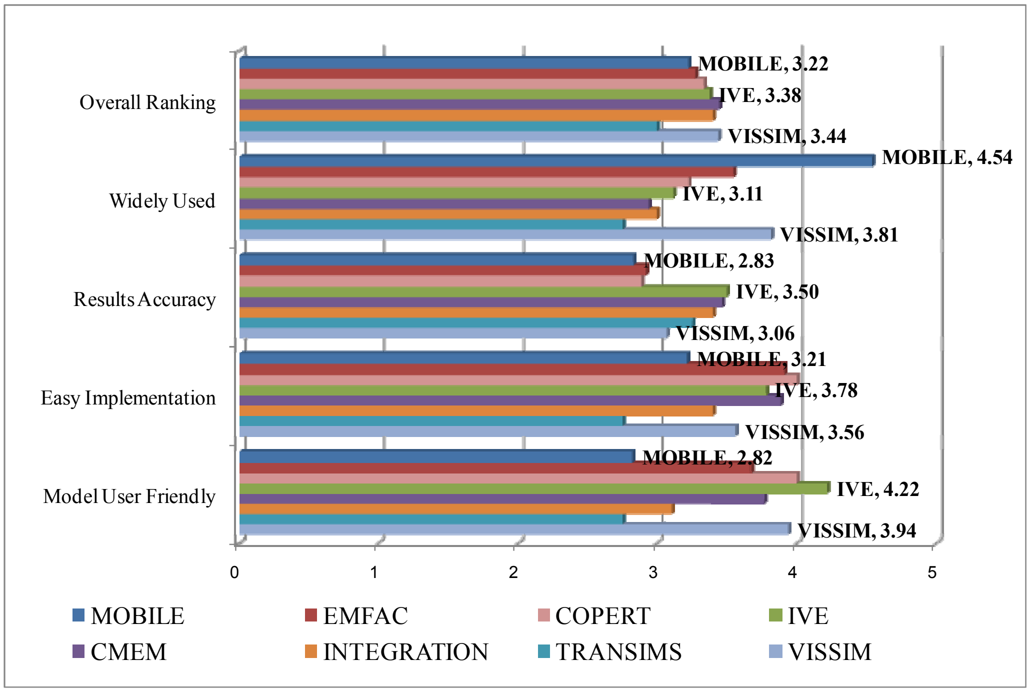

Figure 9 Researchers' Evaluation of Emission Models

For the future preference, 92.73% respondents chose MOBILE from the macroscopic category and 93.54% chose CMEM from the microscopic category. Because the MOVES still has not been fully implemented, it was not listed as a choice purposely in the survey when it asked about future models. However, there are still over 20% respondents who provided an open-ended answer showing they would choose the MOVES anyway. The result implies that emission professionals have a high anticipation of the new generation emission models. Besides the most popular choice, the respondents provided other emission models or transportation models with an emission module as their future choice. These models include TransCAD, CUBE, SYNCHRO, ECOGEST, and PARAMICS. Respondents from Europe provided models like TREMOD and TREMOVE, while respondents from China provided a model named Chinese Emission Model.

For the investigation of model development experiences, around 27.78% respondents indicated that they have experiences in this area. Figure 10 illustrates that 84.62% of these respondents used field collected data as their data source, 46.15% used data provided by local agencies or contractors, 33.33% used data provided by I/M programs and I/M enhancements, and 12.82% used other data sources such as data provided by EPA and fuel data. Further, Figure 11 illustrates that 70.21% agree that the data collection is the most difficult part for developing a model and 65.96% agree that the model calibration and validation is difficult. The respondents also listed the model frame designing, vehicle classification, algorithm designing, and integration with traffic models as hard tasks for the model development. These results indicate that although there are several difficult tasks in the emission model development, the data collection and data reliability (for calibration and validation) are still the fatal problems for the model development.

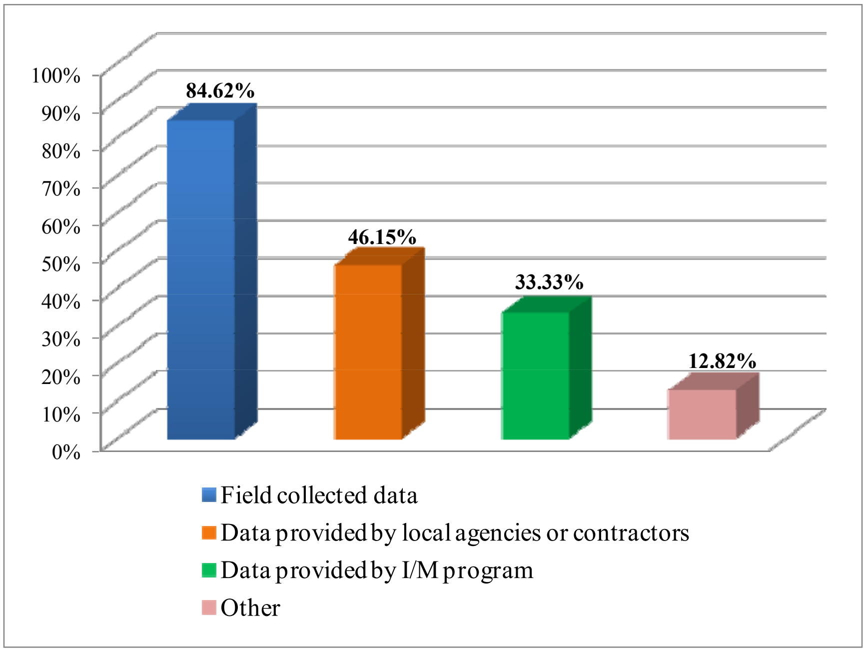

Figure 10 Data Sources of Model Development

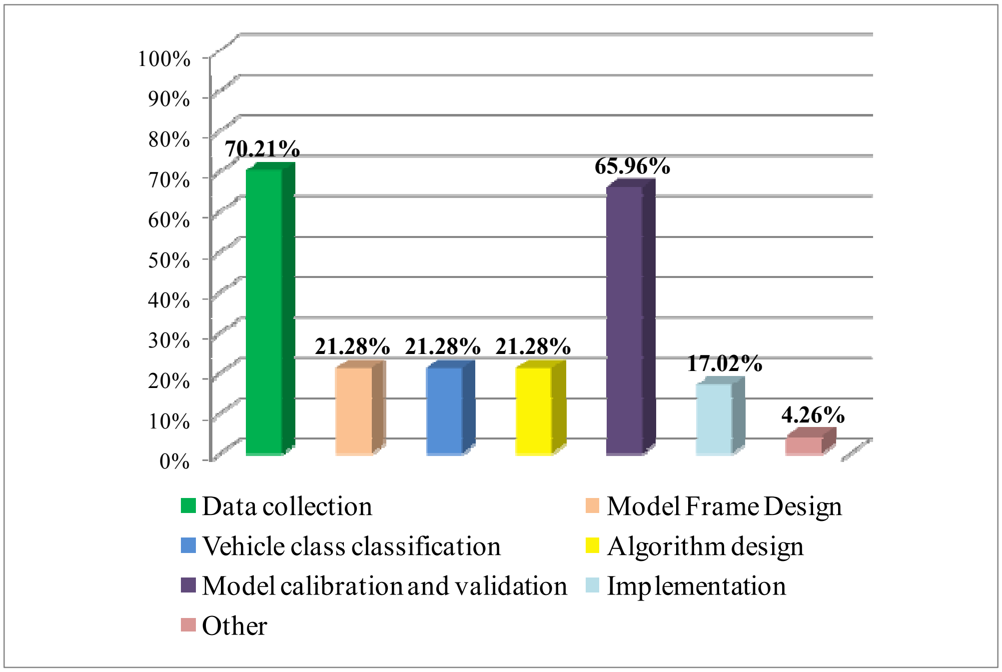

Figure 11 Most Difficult Parts in Developing Emission Models

In terms of evaluating the entire emission modeling system, 52.83% considered the modeling system as good, although they still had to modify the models or develop their own ones. There were 15.09% who thought that the modeling system was fair and they needed to develop models most of the time. There were 13.21% who felt the modeling system was sophisticated with many available choices. However, it is hard to find an appropriate model for specific projects. The comments for the emission models show that emission professionals tend to evaluate the system with neutral positions. They believe the system is fine, but there is not an authoritative model which can be applied to eliminate the impacts of the variability of real-world projects.

With respect to the question whether the existing emission modeling results can truly reflect the emission reduction level caused by emission reduction strategies, 32.08% of the respondents have a positive answer and 67.92% have a negative answer, as shown in Figure 12. Respondents claim that for the particular reduction strategies such as vehicle design and new energy technology improvements, the modeling system works well. However, they believe that the models cannot account for acceleration/deceleration cycles and regional driving behavior changes when evaluating emission reductions caused by transportation operation or land-use improvements. The respondents also indicated that the calibration of the models could be an obstacle for the accurate assessment of the emission reduction.

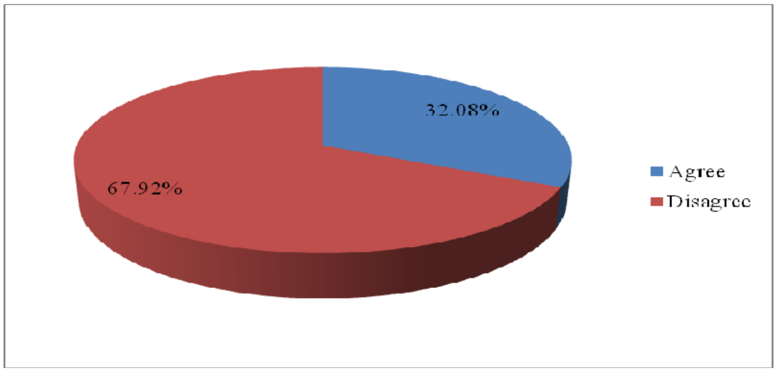

Figure 12 Comments of the Reflection Capability of Emission Models

When asked whether the respondents agree that the existing emission testing and modeling actions can provide enough transportation emission data for further air quality, public health, and economic impact analysis, 54.90% give a positive response and 45.10% give a negative response, as shown in Figure 13. For those who had a negative response, they argued that there is a great uncertainty to analyze the economic impacts of the emissions based on the data collected or estimated because the data cannot truly reflect microscopic realities. They also comment that it is hard to conduct health impact analysis based on the emission data, because the current vehicle testing and modeling does not capture anticipated future concerns very well for ultra fine particulate, mobile source air toxic emissions, and GHG emissions.

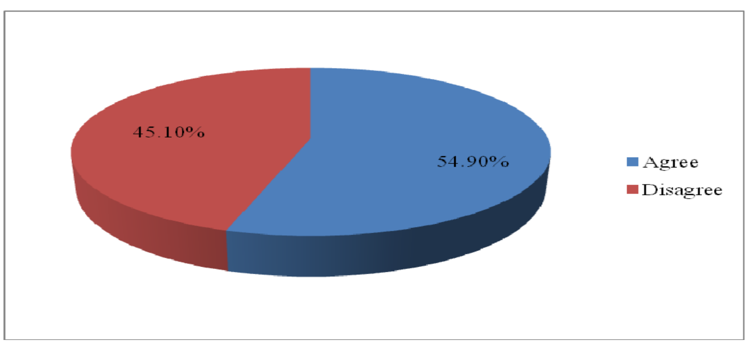

Figure 13 Comments on Analysis Capability of Emission Data

Based on the investigation, HGAC performs on-road mobile source modeling using MOBILE6.2. They indicated that because they perform modeling for SIP and conformity issues, they are always required to use the most up-to-date modeling techniques; therefore, when MOVES (EPA's next mobile source emission model) is released, they will need to switch to it.

4.2.3 Evaluation and Preference of Emission Reduction Strategies

To investigate professionals' comments on the emission reduction strategies, the TSU Survey asked respondents to evaluate the mature level and effectiveness of various emission reduction strategies. The evaluation was designed based on a scoring system with 5 as excellent and 1 as poor. The results and ranking based on the mature level are provided in Table 1.

Table 1 Evaluation of Emission Reduction Strategies-Means of Score

	Mature Level		**Effectiveness**	
Strategies	**Mean Score**	**Std. Deviation**	**Mean Score**	**Std. Deviation**
Vehicle design improvements	3.91	0.91	4.24	0.74
I/M Programs	3.42	1.03	3.42	1.13
Renewable fuel and clean energy	3.36	1.03	3.49	0.90
Traffic signal system optimization	2.90	1.12	2.86	0.85
Ramp metering technology	2.82	1.14	2.54	0.88
Transportation system planning	2.67	0.95	3.13	1.17
ITS technology	2.59	0.95	2.79	1.01
Land use planning	2.46	0.95	2.86	1.18
Other strategies provided by respondents	2.38	1.19	3.50	1.38

According to the survey, the mature level of the reduction strategies was ranked at an order (from most mature to least mature) of vehicle design improvements, I/M Programs, renewable fuel and clean energy, traffic signal system optimization, ramp metering technology, transportation system planning, ITS technology, land use planning, and other strategies provided by respondents. The results reflect that the technologies that were aimed at reducing vehicles emissions are the most mature strategies. This result is consistent with the history of the technology development. The following mature category is the transportation system operation actions. The last mature level was given to the planning strategies. It implies that although planning has a long history, its maturity level in term of emission reduction is still low. The evaluation of the effectiveness yielded a similar order as the mature level. The exceptions are transportation system planning strategy and other strategies provided by respondents. As shown in Figure 14, although the transportation system planning strategy was considered as a less mature strategy to reduce emissions, it was given a positive evaluation for its effectiveness. This indicated that the development of the transportation system planning will benefit the emission reduction. The strategies provided by respondents mostly focused on using the pricing tools, for instance, the congestion pricing or fuel system road pricing to reduce emissions. The respondents thought that although these strategies are not mature currently, they may work effectively if implemented.

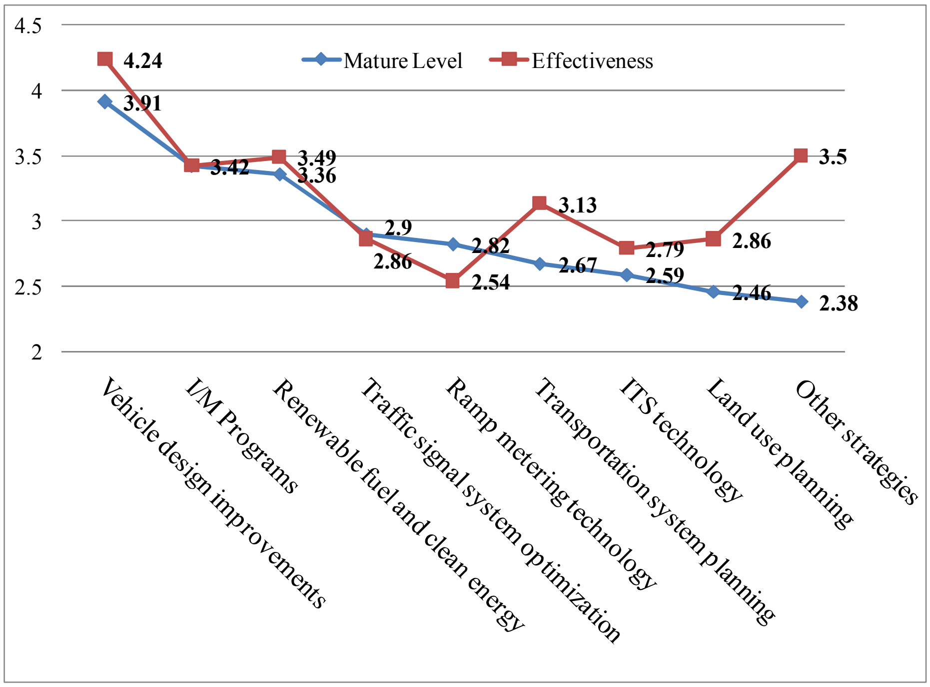

Figure 14 Evaluation of Emission Reduction Strategies

As shown in Figure 15, researchers and all respondents' evaluation of the mature level of the emission reduction strategies are similar although the grades are slightly different for some of the strategies. For instance, the researcher group gave a grade of 2.79 for mature level of the ramp metering strategy, while all respondents gave a grade of 2.90.

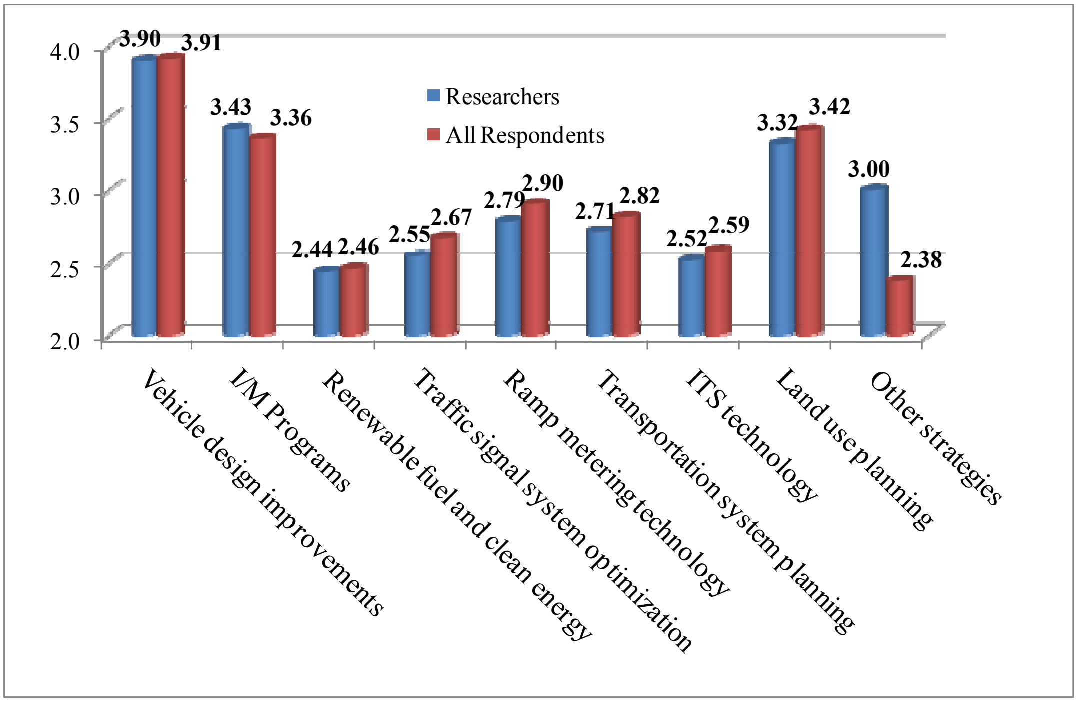

Figure 15 Researchers and All Respondents' Evaluation of Mature Level of Emission Reduction Strategies

As shown in Figure 16, the researchers and all respondents' evaluation of the effectiveness of the emission reduction strategies are similar although the grades are slightly different for some of the strategies. For instance, the researcher group gave a grade of 3.43 for effectiveness of the traffic signal optimization strategy, while all respondents gave a grade of 3.13.

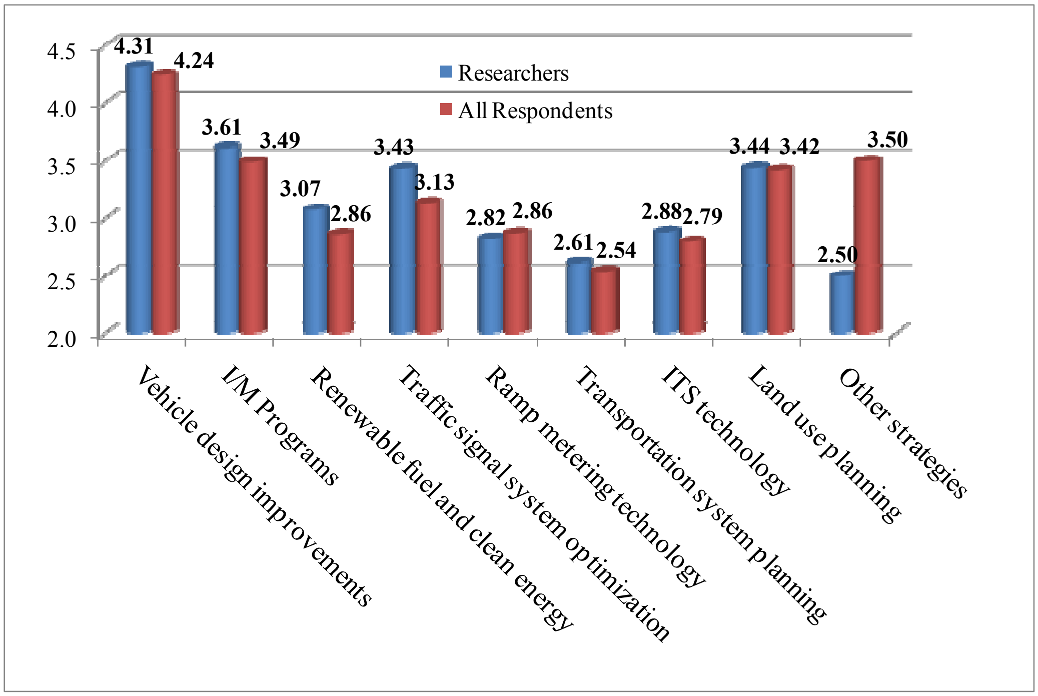

Figure 16 Researchers and All Respondents' Evaluation of Effectiveness of Emission Reduction Strategies

According to the investigation, H-GAC's efforts to reduce transportation related emissions include: Clean Cities/Clean Vehicles, Clean School Bus, Commute Solutions, The Area Emission Reduction Credit Organization (AERCO) and Regional Air Quality Planning Committee (RAQPC). HGAC's evaluation of the effectiveness of its programs generally incorporates factors such as emission reductions achieved, the cost-effectiveness of projects, and the number of participants involved.

4.2.4 Comments of Other Emission Related Topics

To survey the research status of other emission related topics, the TSU Survey investigated professionals' experiences in the emission dispersion modeling and analysis, emission related cost/benefit analysis, and legislative activities.

With respect to the emission dispersion topic, 56.94% indicated that they used dispersion models before, and 77.78% of these people chose the CALINE4 model. Other emission dispersion models provided by the respondents include CAL3QHCR, HYROAD, TRAQSIM, OSPM, SMOKE, CALPUFF, and EDMS. However, some of the respondents indicated that they would rather measure on-road emission benefits than model them.

For the cost/benefit efficiency analysis, only 26.39% showed that they had experiences to do cost/benefit efficiency analysis for their emission projects, but the projects provided by the respondents showed that the cost/benefit efficiency analysis could be applied to many kinds of emission projects, such as evaluation of the I/M programs, transportation operation programs, transit programs and so on.

For legislative activities, only 10% respondents indicated that they were involved in some legislative programs. However, according to all respondents, 40.35% thought that the regulation system was too loose, 38.60% thought it still needed to be improved with specific rules on particular cases, and 21.05% felt it was suitable for present conditions as shown in Figure 17.

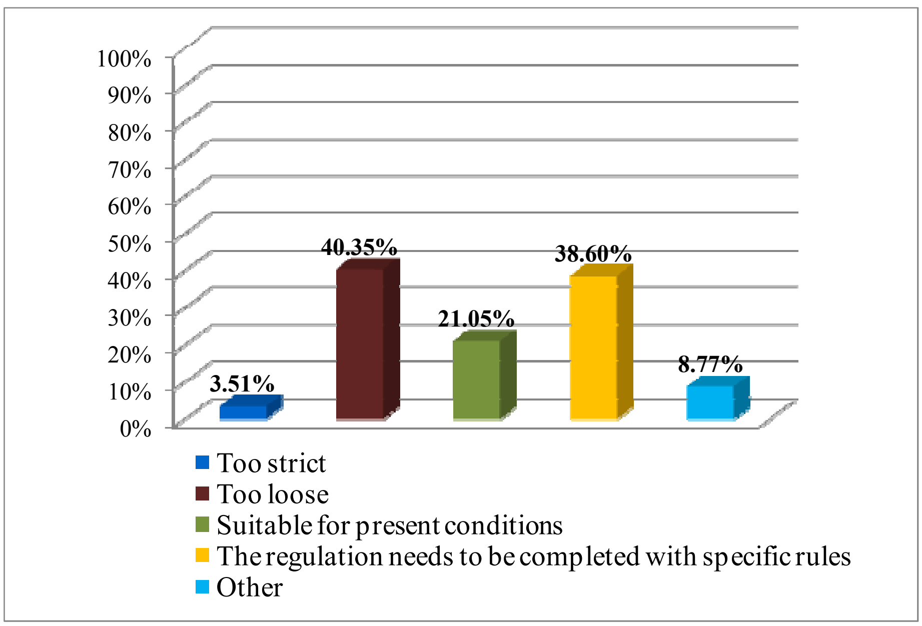

Figure 17 Comments on Current Emission Regulation System

Although the GHG emissions and associated global warming is one of the problems caused by transportation related emissions, the survey shows that there are very few studies focusing on this issue. According to the investigation of HGAC's attitude toward this issue, it indicates HGAC's current efforts are primarily targeted towards reducing ozone pre-cursors (nitrogen oxides and volatile organic compounds), and to a lesser extent, particulate matter. At this time, HGAC does not have any programs targeting GHG emission reductions.

4.2.5 Comments of Future Research Directions

With the reviews of existing transportation related emission research and the results from the TSU Survey, eight research issues were selected and ranked as the most likely future research directions. They are presented at the respondents' preference order as shown in Figure 18.

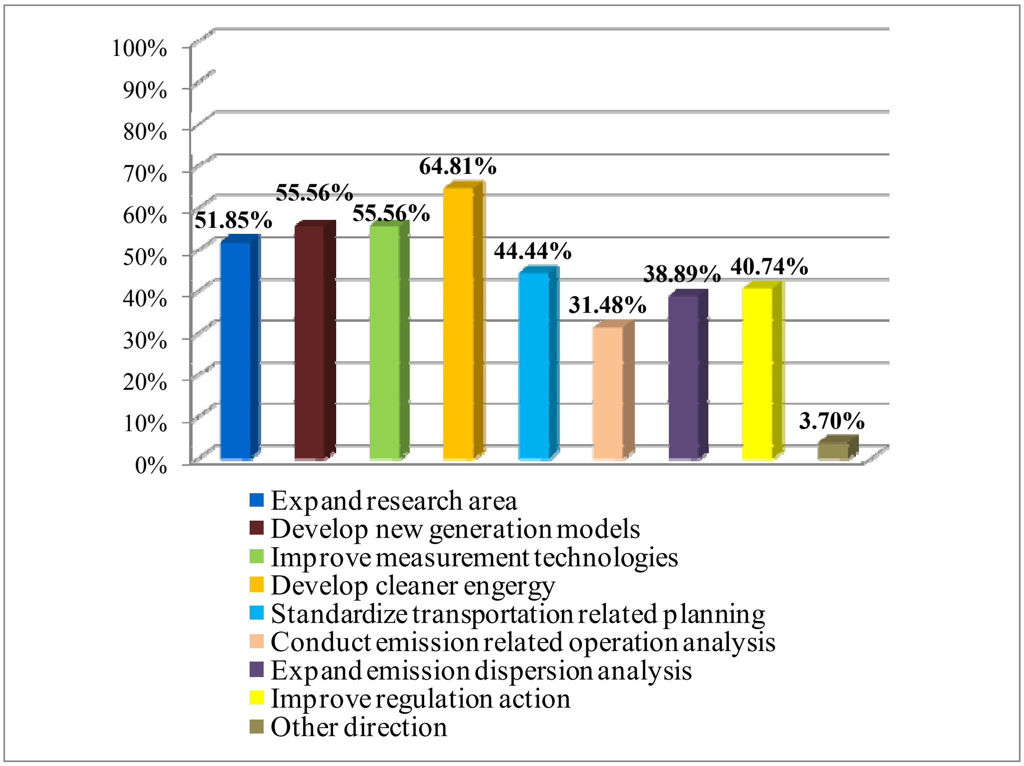

Figure 18 Future Emission Research Directions

The first research direction is to accelerate alternative and clean energy developments. This is the ultimate way to solve the emission problems. There were 64.81% of the respondents in the survey who agree the issue is one of the future directions.

The second research direction is to improve transportation emission measurement technologies. A reliable emission data source is the basic element for other emission research. The key issue recently is to improve the popular PEMS system to satisfy the requirements of technical issues and data reliability for future emission projects and 55.56% agree that this should be one of the future directions.

The third research direction is to develop a new-generation transportation emission model. As reviewed, the emission modeling system is encountering a hard time. The macroscopic models have limitations which make it difficult to be updated and also there is a lack of reliable and widely acceptable microscopic models. To address the problems, EPA released its MOVES Demo version as an update to MOVES 2004 recently. The research and refinement of the software will continue until a reliable new-generation emission model is readyand 55.56% agree that this should be one of the future directions.

The fourth research direction is to expand the transportation emission research area. Although the existing transportation emission research area already covers many aspects, it is not sufficient because the further the research goes; the more it interfaces with other subjects. The emission research needs to interact with environmental science and technologies to evaluate its emission impacts. The research also needs to communicate with social and economic science to control the emissions with social-economic toolsand 51.85% agree that this should be one of the future directions.

The fifth research direction is to improve the transportation emission related land use and transportation system planning. To smooth the traffic and minimize the amount of travel is an effective way to reduce emission. As shown in the survey results, researchers agree the planning strategy to be effective, but argued that the planning is not mature in reducing emissions. It shows a space for the planning to be improvedand 44.44% agree that this should be one of the future directions.

The sixth research direction is to improve transportation emission legislative and regulatory actions. In the survey, 40.74% had positive comments on this direction.

The seventh research direction is to expand transportation emission dispersion and health impacts analysisand 38.89% agree that this should be one of the future directions.

The eighth research direction is to conduct more analysis on the transportation emission related transportation operational improvements. The research should focus on finding better operational mode for emission reduction rather than just evaluating existing operations and 31.48% agree that this should be one of the future directions.

As shown in Figure 19, in terms of forecasting the future research fields, researchers and practitioners have different projections for particular directions. The figure first shows that the two groups of professionals have similar preference of the directions. For instance, they both feel accelerating the alternative and clean energy development is the first priority for the future research; 62.50% practitioners and 57.14% researchers agree with the forecasting. As for the directions of expanding the research areas, developing new generation emission models, improving measurement technologies, and improving transportation emission regulations, almost the same percentage of the researchers and practitioners have the same predictions. However, they have different prospects for the direction of standardizing the emission modeling system and the direction of expanding emission dispersion and health impact analysis. There are 45.71% researchers who believe that standardizing the emission modeling system would be an important direction of the research, while only 33.33% practitioners agree with it. There are 45.83% practitioners who agree that expanding emission dispersion and health impact analysis is important for future research, while only 28.57% researchers predict the same way.

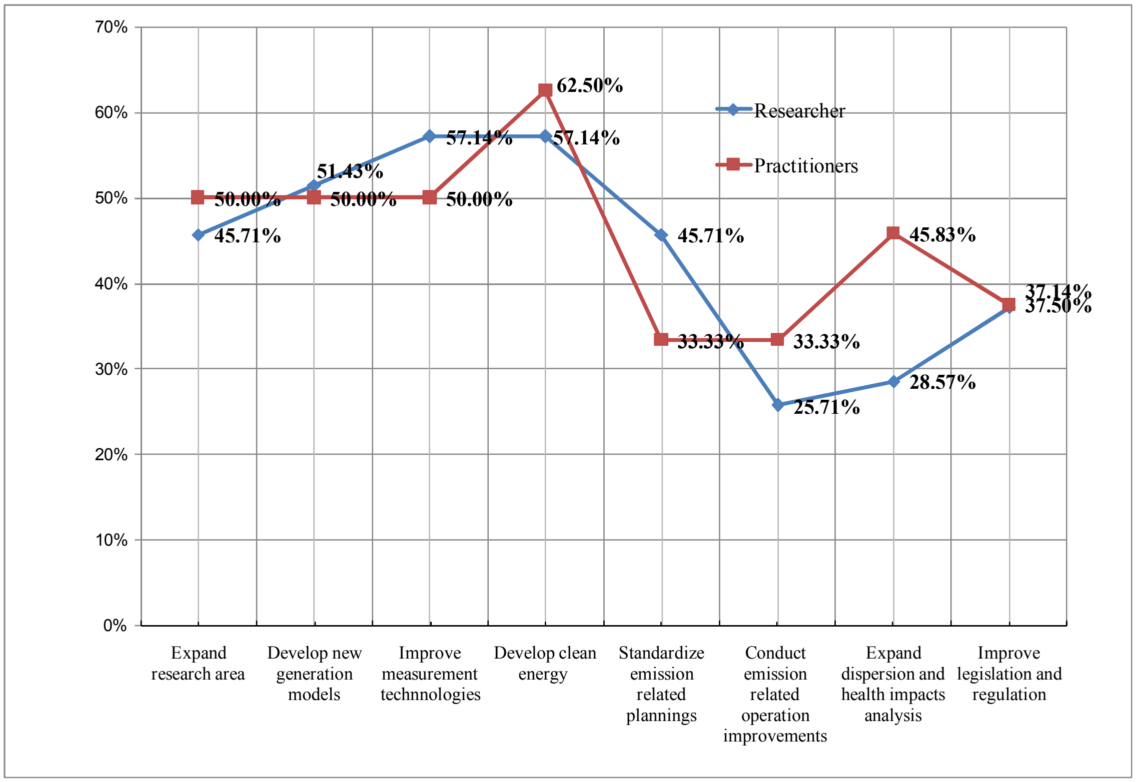

Figure 19 Projections of Future Directions of Researchers and Engineers

CHAPTER 5: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of the Study

Based on the discussion and findings, this report achieved the objectives that follow. The report built connections between research on emissions from transportation sources by synthesizing the studies and findings on different transportation modes. It emphasized the research on inter-modal emission sources. The report serves the goals of mitigating the lack of understanding between transportation research disciplines and air quality or regulation disciplines. It integrated emission studies in all environmental engineering, transportation engineering, transportation and land use planning, and mechanical engineering fields. The report provided a full-scale review of the existing research on transportation related emissions by providing both topic-by-topic and synthesized reviews of the studies. The report investigated and summarized first-hand opinions from researchers using a comprehensive survey to the emission experts. The report projected future emission research directions based on the colligation of review findings and survey results.

5.2 Conclusions

In a summary of the reviews of current research on transportation related emissions and the results of the survey, the report draws the following conclusions.

1. The transportation emission measurement system combines both laboratory and field test methods. It is able to serve the need to measure emissions from a general fleet and individual objectives. The measurement system is experiencing a refinement process from laboratory testing to real-world data collection. Based on the results of the survey, over half of the emission professionals used the PEMS measurement before and will stick to it in the future. Although the dynamometer and driving cycle testing received complaints for its high cost and hard to handle, it is still commented as the most reliable or standard way to measure emissions. Over half of the surveyed

professionals tend to utilize the collected emission data to analyze the impacts of transportation operation on emissions, to develop new emission models, or to analyze impacts of the new emission reducing technologies.

2. Based on the review, the emission modeling system has the ability to model all regional, segment/ facility, and individual levels emissions. Although there are several types of emission models, such as travel based models, fuel based models, and instantaneous models, EPA's old and new generation models are still keeping the status as a reference to emission modeling research and practice. Especially the new generation model, MOVES, will be able to serve the need of all levels. According to the results of the survey, 92.73% respondents chose MOBILE from the macroscopic category and 93.54% chose CMEM from the microscopic category. The result also implies that emission professionals have high anticipation of the new generation of EPA's emission models. In terms of evaluating the entire emission modeling system, 52.83% considered the modeling system as good. However, they still had to modify the models or develop their own ones.
3. According to the review, the emission reduction activities are required by laws and are administrated by federal and state governments. The reduction activities need to involve efforts of governments, manufacturers and customers. The actions make credits in terms of reducing criteria pollutants and GHG emissions. According to the results of the survey, vehicle design improvements was evaluated as the most mature and effective way to reduce transportation emissions. The I/M Programs and renewable fuel and clean energy were commented as effective ways in terms of emission reduction although there are still spaces to improve the mature level of these strategies. The transportation planning and operation strategies were commented as the least mature ones and their effectiveness were also questioned.
4. Transportation emission related issues cover a wide range. The research and practice territory of this topic keeps spreading. It is a multi-task to cover all inter-modal emission controlling, impacts on air quality and environment, regulatory action, and economy impacts analysis. Transportation emission research is becoming a cross-disciplinary subject which combines transportation, planning, chemistry, and environmental studies. According to the results of the survey, professionals show that

they have rich experiences with the emission dispersion modeling system, but very few of them were involved in cost/benefit analysis and legislative programs. For the regulation system, 40.35% of the professionals thought that the regulation system was too loose, 38.60% thought it still needed to be improved with specific rules on particular cases, and 21.05% felt it was suitable for present conditions.

5.3 Recommendations

In light of the findings and conclusions, the report would like to make three recommendations to the future studies of the transportation related emissions.

1. It is recommended that the emission modeling system be synthesized and a new generation of emission models be developed as soon as possible. As reviewed and surveyed, there are numerous emission models and transportation models with the built-in emission estimation modules. However, there is no common preference to any of the models and the results of the estimation vary considerably. Although the EPA's MOBILE series was evaluated with a relatively better reliability and wide acceptance, the regional level estimation restricted the application of the model. With the development of the PEMS and RSD measurement technology, the database will be ready to develop new generation emission models to estimate microscopic level emissions. In this case, the EPA should accelerate the release of its new MOVES model to provide a reference for the modeling research.
2. It is recommended that the transportation professionals be involved in a wider area of the emission studies other than only focusing on the on-road source emission measurement and modeling. The emission research is a cross-disciplinary field. The measurement and modeling is only part of the study. With the collected and estimated emission data, transportation professionals should research more deeply to interpret and utilize the data for the analysis of emission dispersion and reduction actions. A full-scale understanding of the transportation emissions may help transportation professionals apply transportation operation

and planning tools to solve the emission problems and achieve better transportation improvement results in terms of emission reduction.

3. It is recommended that the responsible organizations encourage the public to pay more attention to the GHG emissions and energy efficiency in regards to the transportation emission reduction. The greenhouse effect and global warming has become a major threat to the environment reliability of the earth. Together with the regulation and control of the criteria pollutants, the research should develop more efficient strategies to improve the energy efficiency and to reduce GHG emissions.

APPENDIX A: SURVEY QUESTIONNAIRE

Survey on Transportation Related Emission Research

Department of Transportation Studies
Texas Southern University

Instruction

This survey is designed to complete a study being conducted at the Department of Transportation Studies at Texas Southern University (TSU). The objectives of the survey are to investigate the use and users' evaluation of existing transportation related emission testing techniques and estimation models; identify transportation emission related research topics; determine the gaps in the state-of-the-art/practice in the relevant research area; and establish future research directions related to transportation emission.

The survey is divided into four parts with 30 questions in total. Based on our pilot survey, all questions can be completed in 15-20 minutes. Please try to respond to all questions. If some of the questions are not applicable in your area, please feel free to skip them. All responses to the questions will be used only for research purposes. It is estimated that the results of this survey will benefit all researchers and practitioners in the area of transportation and/or emissions.

To appreciate your cooperation and contribution to this study, we will e-mail you the survey and the analysis results upon completion of this study. If there are any questions about the survey, please contact Dr. Lei Yu (yu_lx@tsu.edu or 713-313-7282) at your convenience.

Part I: Transportation Emission Testing and Modeling

1. For any of your emission related projects, is it necessary to collect the first-hand (field) emission data?
☐ Yes / ☐ No
If yes, please select the emission measurement techniques you have ever used. (Multiple Choice)
☐ a. Chassis/Engine Dynamometer
☐ b. Remote Sensing
☐ c. Portable Emission Measurement Systems (PEMS)
☐ d. Idle /IM240/ Acceleration Simulation Mode (ASM)
☐ e. Other, please specify ______________________________
☐ f. Not Applicable

2. What are the main purposes of your data collection (Multiple Choice)?
☐ a. To calibrate existing emission models
☐ b. To develop new emission models
☐ c. To analyze impacts of transportation operation on emissions
☐ e. To analyze impacts of new fuel on emissions
☐ f. Others, please specify ________________________________
☐ g. Not Applicable

3. Please evaluate the emission measurement techniques/system you have used, with 5 as excellent and 1 as poor.

	Chassis/Engine Dynamometer	Remote Sensing
Equipment easy to handle	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Cost/Benefit Efficiency	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Data Reliability	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Widely Used	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Overall Ranking	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

	Portable Emission Measurement Systems	I/M Program Testing Methods	Other
Equipment easy to handle	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Cost/Benefit Efficiency	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Data Reliability	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Widely Used	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Overall Ranking	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

4. If the field data collection is part of your future task, which of the following techniques/system will you choose? (Multiple Choice)
   ☐ a. Portable Emission Measurement Systems (PEMS)
   ☐ b. Remote Sensing
   ☐ c. Idle /IM240/Acceleration Simulation Mode (ASM)
   ☐ d. Chassis/Engine Dynamometer
   ☐ e. Other, please specify ________________________________
   ☐ f. Not Applicable

5. Have you ever tried to estimate transportation emissions by using any emission models?
   ☐ Yes / ☐ No

If yes, please indicate what types of models you have used. (Multiple Choice)
   ☐ a. Travel based models, such as MOBILE, EMFAC, IVE, etc.
   ☐ b. Fuel based models, such as COPERT.
   ☐ c. Modal and instantaneous emission models, such as CMEM.
   ☐ d. Integration of transportation models and emission models, such as TRANSIMS, INTEGRATION, VISSIM, etc.
   ☐ e. Other, please specify_________________________________
   ☐ f. Not applicable.

6. Please evaluate the estimation models you have used, with 5 as excellent and 1 as poor.

	MOBILE	EMFAC	IVE
Model User Friendly	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Easy Implementation	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Results Accuracy	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Widely Used	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Overall Ranking	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

	CMEM	MEASURE	NETSIM
Model User Friendly	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Easy Implementation	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Results Accuracy	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Widely Used	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Overall Ranking	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

	TRANSIMS	INTEGRATION	VISSIM
Model User Friendly	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Easy Implementation	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Results Accuracy	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Widely Used	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Overall Ranking	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

	COPERT	Others	Others
Model User Friendly	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Easy Implementation	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Results Accuracy	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Widely Used	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Overall Ranking	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

7. Did/will you try to develop a transportation emission model?
   ☐ Yes/ ☐ No

If yes, please

☐ a. List the names of your models__________________________

☐ b. List the emission data source of your models (Multiple Choice)

☐ Field collected data

☐ Data provided by local agencies or contractors, please specify__

____

☐ Data provided by I/M program, please specify_______________

____

☐ Others, please specify __________________________________

8. For your own experience, what are the most difficult parts in developing emission models? (Multiple Choice)
   - ☐ a. Data collection
   - ☐ b. Model Frame Design
   - ☐ c. Vehicle class classification
   - ☐ d. Algorithm design
   - ☐ e. Model calibration and validation
   - ☐ f. Implementation
   - ☐ g. Others, please specify _____________________________________
   - ☐ h. Not applicable

9. If you need to estimate transportation emissions in the future, please select some models you might use. (Multiple Choice)

a. Travel based models

☐ MOBILE ☐ EMFAC ☐ IVE or specify _______________

b. Fuel based models

☐ COPERT or specify _____________________________________

c. Modal and instantaneous emission models

☐ CMEM ☐ MEASURE or specify____________________

☐ d. Integration of transportation models and emission models

☐ TRANSIMS ☐ INTEGRATION ☐ VISSIM or specify___

____

☐ e. I will develop my own model

☐ f. Others, please specify ______________________________________

☐ g. Not applicable

10. Did/ will you conduct any emission research related to aviation or marine emission sources?

☐ Yes/ ☐ No

If yes, please

a. Specify your project____

b. Specify the sponsor of your project______________________________

c. Provide name, email and telephone number of the responsible persons in case we want to get more information on the project.

____

____

Part II: Transportation Emission Related Research Topics

11. Which of the following transportation emission related research topics have you conducted before? (Multiple Choice)

☐ a. Vehicle emission reduction technologies

☐ Vehicle engine/fuel system/catalyst converter/aerodynamic system improvements

☐ Fuel Additive /Alternative Fuel /Clean Energy

☐ b. Planning action on emission control

☐ Land use planning

☐ Transportation system planning

☐ c. Transportation operation improvements and emission reduction

☐ Traffic signal system optimization

☐ Ramp metering technology

☐ ITS technology

☐ d. Implementation/ Maintenance program on emission control

☐ e. Driving cycle impacts on vehicle emission

☐ f. Transportation emission dispersion analysis

☐ g. Transportation emission economic impacts analysis

☐ h. Transportation emission legislation and regulation

☐ i. Others, please specify___________________________________

____

12. Please evaluate the mature level and effectiveness of each emission reduction action, with 5 as excellent and 1 as poor.

Action	Mature Level	Effectiveness
Vehicle engine/fuel system/catalyst converter/aerodynamic system improvements	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Fuel Additive /Alternative Fuel /Clean Energy	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Land use planning	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Transportation system planning	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Traffic signal system optimization	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Ramp metering technology	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
ITS technology	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Implementation/ Maintenance program	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1
Other ______	□5 □4 □3 □2 □1	□5 □4 □3 □2 □1

13. Have you ever conducted any projects related to transportation emission dispersion or air quality evaluation?
☐ Yes/ ☐ No
If yes, please indicate the models you chose for your projects.
☐ CALINE3 ☐ CAL3QHCR ☐ HYROAD
☐ TRAQSIM
☐ Other, please specify____

14. Have you ever conducted any research related to transportation emission cost evaluation or project cost/benefit analysis?

☐ Yes/ ☐ No

If yes, please

a. Specify your project____

b. Briefly describe your evaluation results____________________________

____

15. Have you ever been evolved in any legislative programs using your transportation emission data or theories?
☐ Yes/ ☐ No
If yes, please list these programs ____

16. How do you evaluate the present regulations for transportation emissions?
☐ a. Too strict
☐ b. Too loose
☐ c. Suitable for present conditions
☐ d. The regulation system still needs to be completed with specific rules on particular cases
☐ e. Others, please specify______________________________________
☐ f. No comments

17. Please list all transportation emission related research you have conducted in the past. - ____

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Part III: Transportation Related Emission Research Gaps and Future Development Directions

18. How do you evaluate the existing transportation emission estimation models?
☐ a. The modeling system is consummate. I can predict and calculate emissions at any scope.
☐ b. The modeling system is sophisticated with many available choices. However, it is hard to find an appropriate model for my projects.
☐ c. The modeling system is good. However, I still have to modify the models or develop my own ones.
☐ d. The modeling system is fair. I need to develop my own models most of the time.
☐ e. The modeling system is poor. I have to develop models for all my projects.
☐ f. Other evaluation, please specify ____________________________

____

☐ g. No comment.

19. Are there any specific requirements which cannot be met by using current emission models?

☐ Yes/ ☐ No

If yes, please specify these requirements (such as input data collection cost, model user friendly, results accuracy, etc)?

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____

20. Please evaluate the existing transportation emission measurement techniques.
☐ a. It is always easy to find appropriate measurement techniques to all my projects.
☐ b. It is possible to find appropriate measurement techniques most of the time, but still there is space to improve.
☐ c. It is hard to find an appropriate measurement technique most of the time.
☐ d. It is impossible to find an appropriate testing technique, and I have to design my own testing methodologies.
☐ e. Other evaluation, please specify ____________________________

____

☐ f. No comment.

21. Are there any specific requirements which cannot be met by using the existing testing techniques?

☐ Yes/ ☐ No

If yes, please specify these requirements (such as device availability, data accuracy, data collection cost, etc)?

____

____

22. Do you think there are any gaps existing between transportation emission models and data collection techniques?
☐ Yes / ☐ No
If yes, please specify the gaps____

____

23. Do you think there are any gaps existing between transportation emission testing/modeling and reduction technologies?
☐ Yes/ ☐ No
If yes, please specify the gaps____

____

24. Do you think there are any gaps existing between transportation emission research and air quality evaluation?
☐ Yes/ ☐ No
If yes, please specify the gaps____

____

25. Do you think there are any gaps existing between transportation emission regulations and real-world emission controls?
☐ Yes / ☐ No
If yes, please specify the gaps____

____

26. Which of the following do you think will be the most important future emission research development directions from now? (Multiple Choice)

☐ a. Expanding transportation emission research area

☐ b. Developing new generation transportation emission models

☐ c. Improving transportation emission measurement techniques

☐ d. Accelerating alternative and clean energy development

☐ e. Standardizing transportation emission related land use and transportation system planning

☐ f. Conducting more transportation emission related transportation operation improvements analysis

☐ g. Enhancing and improving the I/M program

☐ h. Expanding transportation emission dispersion and health impacts analysis

☐ i. Improving transportation emission legislation and regulation action

☐ j. Other direction, please specify

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Part VI Background Information

27. Please provide your contact information for further communication and enable us to send you the findings of the study.

Name____________________ Title_________________________________

Division____

Organization____

Address____

City_______________________ State/Zip______________________________

Tel ______________ Fax _____________Email___________________________

28. How many transportation emission related projects have you ever been working on, approximately? ____

Please list the sponsors for your projects_________________________________

29. For how many years have you been working as a professional in transportation emission area? ____

30. In which year/years did/will you conduct any research topics or projects related to transportation emission? ____

APPENDIX B: BACKGROUND INFORMATION OF RESPONDENTS

Respondents	Name	Title	Division	Organization	Location	Email
1	Guohua Song	RA	School of Traffic and Transportation	Beijing Jiaotong University	Beijing, China	songguohua@hotmail.com
2	Fengxiang	Assistant Professor	Department of Transportation Studies	Texas Southern University	Houston, TX	qiao_fg@tsu.edu
3				US DOT		
4	Mohamadreza Farzaneh	Assistant Research Scientist	Center for Air Quality Studies	Texas Transportation Institute	College Station, TX	mfarzaneh@tamu.edu
5				University of Connecticut		
6				US EPA		

7	John Byun, Ph.D.	Air Quality Modeling Specialist	Resource Center	FHWA	Baltimore, MD	Joon.byun@fhwa.dot.gov
8				Michael Baker Corp.		
9	Deng	Professor	Department of Applied Environmental Science	Stockholm University	Stockholm, Sweden	
10				US EPA		
11				Virginia Tech.		
12	Dana Lowell	Senior Consultant		M.J. Bradley Associates	Manchester, UK	dlowell@mjbradley.com
13				University of Illinois at Chicago		
14				US EPA		

15	Kyoungho Ahn			Virginia Tech. Transportation Institute		kahn@vt.edu
16				United Technology Research Center		
17				Embry-Riddle Aeronautical University		
18	Michael F. Lawrence	President		Jack Faucett Associates	Bethesda, MD	lawrence@jfaucett.com
19				University of Virginia		

20	Jeroen Van Houtte	GSR	ITS	UC Davis	Davis, CA	jjvanhoutte@ucdavis.edu
21					Houston, TX	
22	Lin Xin		Environmental Engineering	Tsinghua University	Beijing, China	linx@mails.tsinghua.edu.cn
23	Angela_Xu				Beijing	angelax0160@sina.com
24	Robert Noland		Centre for Transport Studies	Imperial College London	London, UK	r.noland@imperial.ac.uk
25	Sudarmanto	mr	Transportation Engineering	Hiroshima University	Japan	totoksbn@hiroshima-u.ac.jp
26	Jungwook Jun	Traffic Engineer	Traffic Engineering Division	VDOT		jungwok.jun@vdot.virginia.gov
27				North Carolina Research and Education		

28	Sangjun Park	Graduate Student	CEE	VPI	Blacksburg, VA	sangjun@vt.edu
29	Jens Borken		Transportation Research	DLR		
30				National Renewable Energy Laboratory		
31	Julia Gamas	Post-Doc	APPCD	US EPA		gamas.julia@epa.gov
32	Donald Lyons	Professor & Co-director	Cent. Altern. Fuels, Engines, Emissions	West Virginia University	Morgantown, WV	dwlyons@mail.wvu.edu
33	David Hyder	Transportation Planning Administrator		City of High Point	High Point, NC	david.hyder@highpointnc.gov
34				CARB		

35	Tiago Farias	Professor	Mechanical Engineering	Instituto Superior Tecnico	Lisbon, Portugal	tiago.farias@ist.utl.pt
36	Doh-Won Lee	Assistant Research Scientist	Center for Air Quality Studies	Texas Transportation Institute	College Station, TX	leedw@tamu.edu
37					Dallas	
38	Shiwu Li	Professor	Traffic Environment	School of Traffic &Transportation, Jilin University	Changchun, China	shiwu@jlu.edu.cn
39	Fang Yang			Beijing Jiaotong University	Beijing, China	

40				Iowa State University		
41	Jesse Mayes	Air Quality Specialist	Planning	Kentucky Transportation Cabinet	Frankfort, KY	jesse.mayes@ky.gov
42					Washington D.C.	
43	Shuxia Guo	PH.D. Candidate	School of Traffic and Transportation	Beijing Jiaotong University	Beijing, China	guoguoshuxia@163.com
44	James Hao	PH. D. candidate	School of Traffic and Transportation	Beijing Jiaotong University	Beijing, China	haoyz828@163.com
45	John Suhrbier	Principal		Cambridge Systematics, Inc.	Cambridge	JSuhrbier@camsys.com
46	Li Tiezhu	Associate Professor	Transportation College	Southeast University	Nanjing, China	litiezhu@seu.edu.cn

47				Rutgers, University		
48				Cornell University		
49	Joe Zietsman	Associate Research Engineer	Center for Air Quality Studies	Texas Transportation Institute	College Station, TX	zietsman@tamu.edu
50	Nagui Rouphail	Director	Institute for Transportation Research and Education		Raleigh, NC	
51				University of California, Riverside		
52				West Virginia University		

53	Nino Brunello	Transportation Engineer	Planning	Ohio DOT	Columbus, OH	Nino.Brunello@dot.state.oh.us
54		PhD student	Transportation Planning	University of Toronto		
55	Linda Gaines	Systems Analyst	Energy Systems	Argonne National Laboratory	Argonne, WI	lgaines@anl.gov
56	Margarida Coelho	Assistant Professor	Department of Mechanical Engineering	University of Aveiro	Aveiro	margarida@mec.ua.pt
57	Mia Waters	Air Quality, Acoustics & Energy Programs Mgr.	Environmental Services	Washington State Dept of Transportation	Seattle, WA	watersy@wsdot.wa.gov
58	Jeff			Integra Telecom, Inc.		jkim@shurepower.com

59	Scott Herndon	Principal Scientist	CAEC	Aerodyne Research, Inc	Billerica, MA	herndon@aerodyne.com
60				Department of Environment Quality, Virginia		
61	Don Stedman	Professor	Department of Chemistry	University of Denver	Denver, CO	dstedman@du.edu
62	Michael Krimmer			George Mason University	Fairfax, VA	mkrimmer@gmu.edu
63	Madhusudhan Venugopal	Transportation Planner III				mvenugopal@nctcog.org
64	Matt Barth	Director	CE-CERT	UC Riverside	Riverside, CA	barth@cert.ucr.edu
65				Michael Baker Corp.		

66	Yi Qi		Department of Transportation Studies	Texas Southern University	Houston, TX	
67				HDR INC		
68	James Lents	President		ISSRC	Diamond Bar, CA	jimlents@issrc.org
69	Zhou Yu		Department of Environmental Science and Engineering	Tsinghua University	Beijing, China	zhouyu97@gmail.com
70	Haikun Wang	PhD candidate	Air pollution control Division, Department of Environmental Science and Engineering	Tsinghua University	Beijing, China	whk06@mails.tsinghua.edu.cn
71	Lei Yu	Professor and Chair	Department of Transportation Studies	Texas Southern University	Houston, TX	yu_lx@tsu.edu

72	Ziqianli Wang	Graduate Research Assistant	Department of Transportation Studies	Texas Southern University	Houston, TX	wangz@tsu.edu

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