United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
CINCINNATI, OH 45268

Research and Development

EPA/600/SR-98/097 August 1998

EPA

Project Summary

A GIS-Based Modal Model of Automobile Exhaust Emissions

William H. Bachman

Suburban sprawl, population growth, and auto-dependency have been linked, along with other factors, to air pollution problems in U.S. metropolitan areas. Addressing these problems becomes difficult when trying to accommodate the needs of a *growing* population and economy while simultaneously *lowering* or maintaining levels of ambient pollutants. Growing urban areas must, therefore, continually develop creative strategies to curb increased pollutant production.

The report presents progress toward the development of a computer tool called MEASURE, the Mobile Emission Assessment System for Urban and Regional Evaluation. The tool works toward a goal of providing researchers and planners with a way to assess new mobile emission mitigation strategies. The model is based on a geographic information system (GIS) and uses modal emission rates, varying emissions according to vehicle technologies and modal operation (acceleration, deceleration, cruise, and idle). Estimates of spatially resolved fleet composition and activity are combined with situation-specific emission rates to predict engine start and running exhaust emissions. The estimates are provided at user-defined spatial scales. A demonstration of modal operation is provided using a 100 km^2 study area in Atlanta, Georgia. Future mobile emissions modeling research needs are developed from an analysis of the sources of model error.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Suburban sprawl, population growth, and auto-dependency have been linked, along with other factors, to air pollution problems in U.S metropolitan areas. Accordingly, the Clean Air Act and other federal legislation and regulations require metropolitan areas to develop strategies for reducing air pollution where air quality standards are exceeded. An emissions 'budget' is established in metropolitan areas that provides a benchmark for comparing new emission-generating activity, and presumably not exceeded. Such a goal becomes difficult when trying to accommodate the needs of a *growing* population and economy while simultaneously *lowering* or maintaining levels of ambient pollutants. Growing urban areas, therefore, must continually develop creative strategies to curb increased pollutant production. Because the largest contributor of pollutant emissions in urban areas has most often been transportation (or mobile) sources, transportation is targeted for new control strategies.

Developing measures of effectiveness and subsequent predictions of overall impact for control strategies require an understanding of the relationship between *observable* transportation system characteristics and emission production. Quantifying this effectiveness requires modeling these relationships. According to published research, motor vehicle emission rates are correlated to a variety of vehicle characteristics (weight, engine size, emission control equipment, etc.), operating modes (idle, cruise, acceleration, and deceleration), and transportation system conditions (road grade, pavement condition, etc.). Exhaust emissions are produced when a vehicle is started and while it is operating. Pollutants produced from starting a vehicle can be predicted using vehicle characteristics. Running exhaust emissions additionally require estimates of dynamic engine conditions that result from how the vehicle is driven. Estimating motor vehicle emissions requires the ability to predict or measure these parameters for an entire region at a level of spatial and temporal aggregation fitting the scope of control strategies. Current modeling approaches, however, cannot provide these estimates.

Emission Modeling

Today's motor vehicle emission modeling process is based on four separate models: a travel demand forecasting model, a mobile emission model, a photochemical model (for emission inventory), and a microscale model (for analyzing transportation improvements). The travel demand forecasting model uses characteristics of the transportation system and socioeconomic data to develop estimates of road-specific traffic volumes and average speeds. Mobile emission models use these travel demand estimates, operating fleet model year distributions, and environmental conditions to develop estimates of mobile source pollutant production. These estimates are fed into photochemical models (along with stationary source estimates and data regarding atmospheric conditions) and are used to predict ambient pollutant levels in space and time. These mobile source estimates can then be used by microscale models to predict pollutant levels near specific transportation facilities.

Several problems with the four-model system limit effective evaluation of motor vehicle emission control strategies. First, the estimates of vehicle activity (vehicle miles traveled and average speed) lack the accuracy and spatial resolution needed to evaluate control measures. Second, the mobile source emission rate modeling process uses highly aggregate fleet average emission rates which are not specific for the fleet in operation, mode of vehicle operation, or grade of the highway facility. As a consequence, the current modeling system has limited capabilities for meeting the modeling requirements of transportation planners. Transportation planners and environmental assessment and control officials have need for improved models that help identify the impacts of standard transportation system improvements (e.g., lane additions, signal timing, peak-hour smoothing).

While many researchers agree that new models and processes need to be developed to overcome these problems, they disagree over the best approach. The U.S. Environmental Protection Agency and the Federal Highway Administration held a workshop in Ann Arbor, Michigan, in May 1997, to identify and discuss current emission modeling research efforts. After the workshop, it was clear that defining appropriate model aggregation levels is important in defining how and what research should be conducted. A point of departure between the largest vehicle emissions research efforts (University of California at Riverside, and the Georgia Institute of Technology) and the currently mandated approach (MOBILE5a) is the level of aggregation required. Figure 1 shows the spectrum of possible approaches. It shows that highly aggregate approaches limit explanatory power, but have reduced data intensity. Disaggregate models have the most explanatory power, but the highest data needs. An added dimension of the issue is that estimates must be spatially and temporally resolved, suggesting that an undefined level of spatial and temporal aggregation must also be defined. In fact, the level of spatial and temporal aggregation of mobile source emissions needed by photochemical models may help define the minimum level of model aggregation currently being debated.

The report presents a *research* model that can guide future mobile emissions model development efforts. A major objective of the model is to incorporate the latest transportation / air quality findings at a low level of spatial aggregation (restricted only by data availability). Creating a model under these guidelines develops information that leads to the maximum level of disaggregation given user needs and data availability. The research model will be comprehensive, flexible, and user oriented. It includes enhanced vehicle activity measures: starts, idle, cruise, acceleration, and deceleration. Vehicle tech-

Emission Rates

Average Fleet (g/trip)	Vehicle Class Average Speed (g/mi)	Tech Groups[a] Vehicle Mode (g/sec)	Tech Groups[a] Vehicle Mode (g/sec)	Individual Vehicles Vehicle Mode (g/sec)	Individual Vehicles Engine Mode (g/sec)
<					>
Aggregate					Disaggregate
Total Trips/Day	Vehicle Class VMT[b] Mean Link Speeds	Tech Group Speed/Accel. Profiles	Tech Group Traffic Flow Simulation	Vehicle Activity Simulation	Vehicle/Engine Activity Simulation

Vehicle Activity

[a] Tech groups refer to sets of vehicles with similar emission characteristics.
[b] Vehicle miles traveled.

Figure 1. Spectrum of modeling approaches.

nology characteristics (model year, engine size, etc.) and operating conditions (road grade, traffic flow, etc.) are developed at a large scale (small zones and road segments). Flexibility is achieved through a modular design that separates emission production based on thresholds determined in background research. Due to large gaps in the state of knowledge, technology, and practice regarding travel behavior, emission rates, and the urban system inventory, the accuracy of the model results remains unvalidated and therefore unknown. However, the model contributes to transportation and air quality research in that it aids research and software development.

The intended model users include emission science experts, model developers, transportation planners, policy makers, and government researchers. Each user group has specific modeling interests that define how the model should be designed and presented. Central to the model design is a geographic information system (GIS).

GISs are widely used computer tools that allow geographically referenced data to be organized and manipulated. Both transportation and air quality vary in spatial dimensions. Thus, GISs have the conceptual capability to manage the relationships between transportation activity and resulting air quality changes based on their spatial characteristics. Further, GISs are already used by most planning organizations in government institutions. Thus, a GIS-based emissions modeling framework fits the character of emission science as well as the technical environment of the expected users.

The variables included in the proposed research model are those whose relationship to vehicle activity and emission rates has been defined in research and is available to public agencies. They can be categorized as:

Spatial Character:
- U.S. Census block boundaries
- Land use boundaries
- Traffic analysis zone boundaries (from travel demand forecasting model)
- Grid cell boundaries (defined by user)
- Road segments (by classification)
- Travel demand forecasting network links
- Grade school and university locations

Temporal Character:
- Hour of the day

Vehicle Technology:
- Model year
- Engine size
- Vehicle weight
- Emission control equipment
- Fuel injection type

Modal Activity:
- Idle
- Cruise
- Acceleration
- Deceleration

Trip Generation:
- Home-based work trips
- Home-based shopping trips
- Home-based university trips
- Home-based grade school trips
- Home-based other trips
- Non-home-based trips

Road Geometrics:
- Number of lanes
- Grade

Socioeconomic Characteristics (for spatial allocation only):
- Housing units
- Land use (residential, nonresidential, and commercial)

Summary of Contributions to Research

- *An automobile exhaust emissions model is developed maximizing comprehensiveness, flexibility, and user friendliness.*

Comprehensiveness is ensured by including variables and procedures identified in the literature as significant to emission rate modeling. Flexibility is achieved by organizing the model components by geographic location, and by maintaining a modular program design. User friendliness is achieved by including only current data available to planning agencies, and by using a GIS framework.

- *A research tool is provided that allows for testing variable levels of motor vehicle emission model spatial aggregation.*

By having the flexibility to use a variety of spatial entities, the model can become a testbed for determining the spatial resolution needed for future models. This information is valuable in identifying future research needs, costs of emission estimation, model development, maintenance, and operation. A question this model could be used to help answer would be, "Given the current state of research, does a 1 km^2 aggregation of ozone precursors provide enough resolution to predict ozone formation, or would a 4 km^2 aggregation be better?"

- *The benefits of using GIS for emissions modeling are demonstrated.*

GISs provide the ability to organize data by location, in turn providing the capability to develop relationships with new or existing spatial datasets. This allows the development of creative alternatives to model construction and provides the ability to prioritize emission control strategies based on location.

- *Research and data needs for improved spatial and temporal emissions modeling are identified.*

A study of background research into emissions modeling, coupled with an analysis of data available in Atlanta, will determine gaps in important emission-specific variables. Further, a prioritization of the data needs based on balancing explanatory power and cost will guide future model development.

Report Organization

Chapter 1 presents an introduction to the report and provides an overview of the research being presented to the reader. Chapter 2 discusses background research significant to automobile exhaust emission modeling, vehicle activity modeling, and GISs. It also identifies a research foundation of knowledge that is used to develop model parameters. Chapter 3 presents a conceptual model design that serves as the foundation of the research approach. Accuracy, comprehensiveness, user needs, and enterprise awareness are important considerations in developing this conceptual model. Chapter 4 provides a physical model structure that can be used as a research tool. The model will reside in a UNIX operating system and use *Make,* the *C* programming language, and *ARC/INFO*. A step-by-step guide to model use is also provided. Chapters 5 and 6 present and analyze a model implementation for a 100 km^2 area in Atlanta. Each module of the system is studied using sensitivity analysis or a comparison of observed data. Chapter 7 discusses data needs and presents final conclusions. An expanded model diagram demonstrates how future vehicle types and operating modes can be added to the system. Chapter 8 lists references cited in the report, and Appendix A is a data dictionary.

W. Bachman is with the School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332.
***Carl T. Ripberger** is the EPA Project Officer (see below).*
The complete report, entitled "A GIS-Based Modal Model of Automobile Exhaust Emissions," (Order No. PB98-165145; Cost: $44.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

EPA/600/SR-98/097