EPA's Plan for MOVES:
A Comprehensive Mobile Source Emissions Model

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ABSTRACT

EPA is developing a new mobile source emissions model that is comprehensive in source category, pollutant and analysis scale. A primary impetus for this effort is the National Research Council's review of EPA's mobile source modeling program, published in 2000, which recommended a) the development of a modeling system more capable of supporting smaller-scale analyses; b) improved characterization of emissions from high-emitting vehicles, heavy-duty vehicles, and off-road sources; c) improved characterization of particulate matter and toxic emissions; d) improved model evaluation and uncertainty assessments; and e) a long-term planning effort coordinated with other governmental entities engaged in emissions modeling. A cross-agency team representing OTAQ, OAQPS, ORD and Regional offices published an initial proposal to address these recommendations in April 2001. Since then, work has progressed on developing a conceptual design and software framework for the new modeling system. This design has been informed by recent advances in subregional emissions modeling and considers how the new mobile source emissions model should interact with new generation transportation and air quality models. Other important considerations of the design are how to capitalize on methods for improved characterization of in-use emissions, such as on-board emissions measurement, and how to incorporate model validation and uncertainty evaluation into the model structure. We present the latest information on a design and implementation plan for the model.

1 INTRODUCTION

Under the Clean Air Act, EPA is charged with developing emission factors for all emission sources. Pursuant to this charge, EPA's Office of Transportation and Air Quality (OTAQ) has developed a number of emission factor estimation tools for mobile sources: MOBILE (for on-road VOC, CO and NOx), PART (for on-road particulate matter and SOx), MOBTOX (for on-road toxics), and NONROAD (for off-road mobile source pollutants). The Multiscale Motor Vehicle and Equipment Emission System (MOVES) is intended to include and improve upon the capability of these tools and eventually to replace all of them with a single, comprehensive modeling system.

Historically, EPA's mobile source emission estimation tools and underlying emission factors have been focused on the estimation of mobile source emissions based on average operating characteristics over broad geographical areas. Examples of this scale of analysis are the development of SIP inventories for urban nonattainment areas and the estimation of nationwide emissions to assess overall trends. In recent years, however, analysis needs have expanded in response to statutory requirements that demand the development of finer-scale modeling approaches to support more localized emission assessments. Examples include "hot-spot" analyses for transportation conformity, and evaluation of the impact of specific changes in transportation systems (e.g., signalization and lane additions) on emissions.

A thorough review of EPA's mobile source modeling program was published by the National Research Council (NRC) in 2000.[1] We have adopted most of the NRC's recommendations as our objectives. These objectives include coordination with stakeholders, applicability to a wide range of spatial and temporal scales, inclusion of all mobile sources and all pollutants, addressing model validation and the calculation of uncertainty, ease of updating the model, quality assurance, interfacing with other models, and ease of use. These objectives have shaped our development plan for MOVES, as detailed in the rest of this paper.

We have begun and will continue to develop MOVES with extensive coordination and outreach. A cross-agency team representing OTAQ, the Office of Air Quality Planning and Standards (OAQPS), the Office of Research and Development (ORD) and Regional EPA offices produced an issue paper containing an initial proposal for the model in April 2001.[2] Since then, we have coordinated with States, metropolitan planning organizations, the U.S. Department of Transportation, consultants, academics, and the Modeling Workgroup of the Mobile Source Technical Review Subcommittee (MSTRS) of the Clean Air Act Scientific Advisory Committee (CAASAC), a committee of experts from government, industry, and academia. This continuing coordination will enable MOVES to benefit from advances in mobile source emission modeling and to meet the needs of the user and stakeholder community.

The April 2001 issue paper defined three basic analysis scales for MOVES. Macroscale analyses are appropriate for developing large-scale (e.g., national) inventories, for which the basic spatial unit would be the county. Mesoscale analyses are appropriate for generating local inventories at a finer level of spatial and temporal resolution, using as spatial units roadway links and traffic analysis zones or using vehicle trips consistent with output from standard travel demand models. Microscale analyses allow the estimation of emissions for specific corridors and/or intersections, which is appropriate for assessing the impact of transportation control measures and for performing project-level analyses.

This paper presents EPA's progress to date on MOVES, focusing on initial efforts regarding model design, emission analysis, software development, and quality considerations. Section 2 describes "use cases", which are a listing and analysis of the ways MOVES will actually be used. Section 3 outlines how the conceptual design will fulfill the use cases. Section 4 presents progress to date in developing a method for estimating emissions at multiple analysis scales, focusing on the analysis of data from multiple data sources, including on-board emissions measurement systems. We describe our progress and plans for using the best modern software design and development techniques in Section 5. Our plan for assuring model quality is presented in Section 6. The current implementation plan and time line is described in Section 7.

2 USE CASES

The preparation of "use cases" is considered a first step in software design, and follows from a basic assessment of model needs. The development of use cases consists of identifying who the real users of the software will be and systematically assembling all the ways that these users need to or would like to use the software. We began by putting together a broad list of use cases, informed by the NRC report and the discussion of model needs in the April 2001 issue paper. With the help of a contractor (MCNC), we interviewed expert users for each use case[3] and identified several ways of organizing these use cases:

Categories by broad purpose:

- Inventory development for EPA reports and regulations (e.g., National Air Quality and Emissions Trends Report and rulemaking regulatory impact analyses).
- Inventory development for regulatory requirements (e.g., SIPs, Conformity, Rate of Progress).
- Policy evaluation (e.g., technologies, fuels, travel controls/incentives, scrappage programs).
- Hot spot and project level analysis.
- Model validation and uncertainty.
- Model updates and expansion.

Categories focused on model input and output:

- Macroscale, mesoscale, microscale analyses, each of which requires different inputs.
- Uses in which inputs and outputs are exchanged with other models (e.g., travel models, emissions processors, dispersion models).

Categories focused on user interaction:

- A powerful and versatile GUI and also a batch, command-line interface.
- Flexibility of input and output formats.
- Output processing (e.g., uncertainty and sensitivity analysis, visualization, comparison of inventories).
- Users who have invested heavily in custom scripts and software to work with MOBILE want to be able to move seamlessly to MOVES.

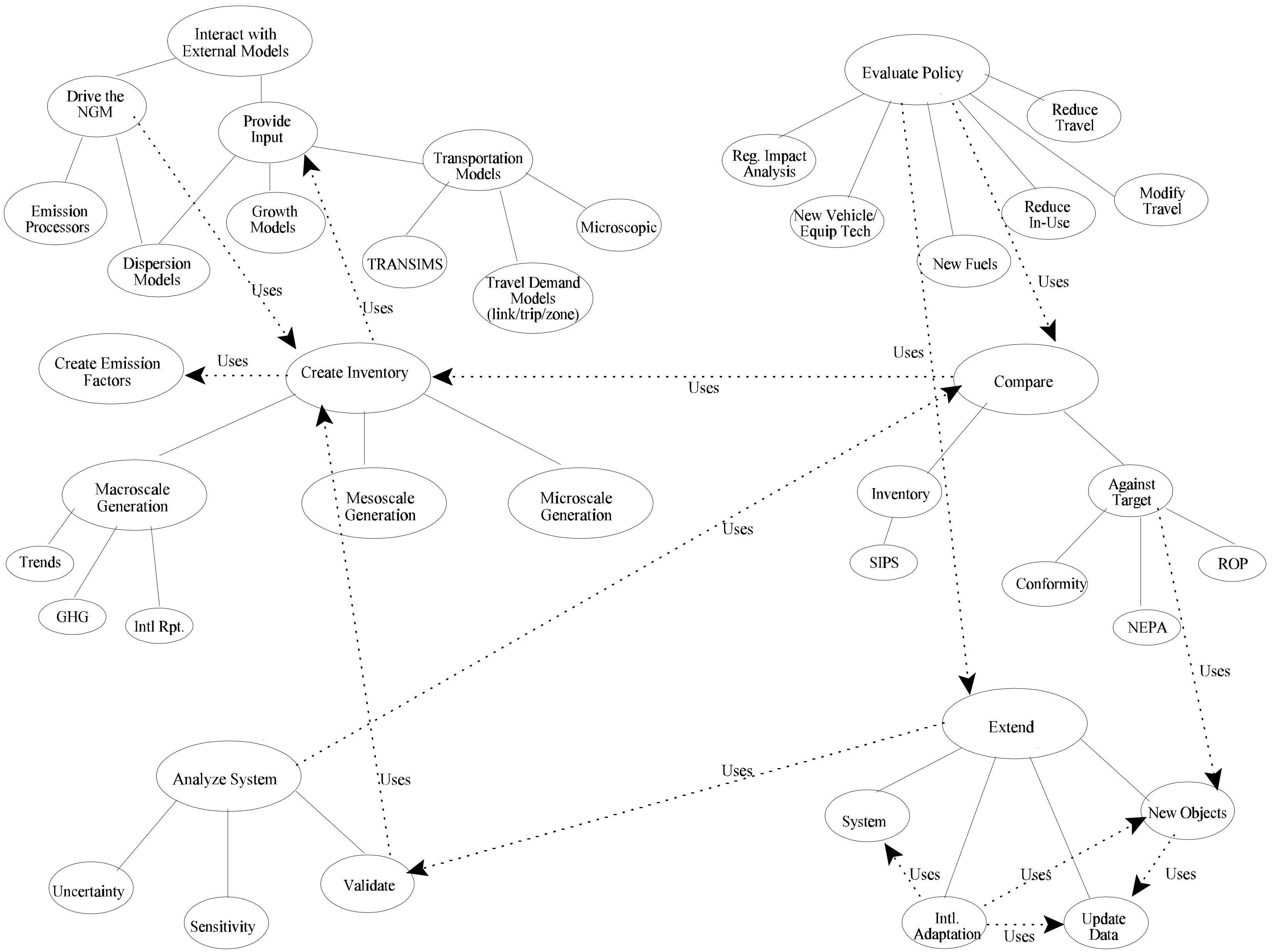
A use-case diagram, shown in Figure 1, was developed by MCNC to represent the relationships between the identified use cases. The principal use case is "Create Inventory", which in turn uses "Create Emission Factors". "Create Inventory" can occur at three scales: macroscale (county-level input data), mesoscale (input data from travel models for links and travel analysis zones), and microscale (observational data for individual intersection or equivalent). "Evaluate Policy" is a tool to evaluate the range of mobile source emission mitigation strategies, from tailpipe emission regulations to traffic control measures. "Compare" is a use case allowing comparison of two inventories or the comparison of an inventory against a target (e.g., for a rate of progress assessment). "Interact with External Models" is a utility use case, which exists to serve the frequent need for MOVES to obtain inputs from, or deliver outputs to, another model. "Analyze System" comprises uncertainty analysis, sensitivity analysis, and model validation. Finally, "Extend" handles the need to extend the model, for example, by inclusion of a new vehicle type, and to update the model with new data, which we expect to do regularly. The other use cases on the diagram are extensions of these main ones. For example, "New Fuels" extends "Evaluate Policy".

The use cases and the diagram represent the potential universe of ways that users would likely want to be able to use MOVES; however, it should not be assumed that all these use cases will be fulfilled in early releases of the model. We intend to develop MOVES in an iterative fashion, meaning that the earliest releases of the model will focus on the most important use cases and expand over time, an approach reflected in our implementation plan discussed in Section 7. In keeping with our iterative paradigm of software development, we do not consider the use case issue closed. We feel that we have obtained a good overview in this first round, but we expect there to be refinements, additions, and perhaps removals as we proceed with model development.

3 CONCEPTUAL DESIGN

To facilitate the discussion, we begin with some definitions. Since MOVES will include both on-road and off-road vehicles and equipment, we define "vehicles" to mean "vehicles and equipment". For a given emission process (see Table 1 below), we denote the vehicle population subcategories that differentiate emissions as "fleet bins", covering categorizations such as vehicle class, age, technology , standard, etc. We denote activity categories that differentiate emissions as "operating modes", and we include "parked" (not operating) as an operating mode. By "emission rates" we mean the most disaggregated rates the model produces internally by fleet bin and operating mode. By "emission factors" we mean emission rates aggregated in various ways over fleet bin and/or operating mode and normalized by some activity basis, such as mass of pollutant per time or per mile.

Figure 1. MOVES Use-Case Hierarchy. The solid lines indicate that the use case below is an extension or specialization of the use case above it. The dotted lines indicate that the use case at the tail of the arrow uses the use case at the head of the arrow.



The emission processes that will be addressed in MOVES are listed in Table 1 below.

Table 1. Emission processes that will be included in MOVES.

Combustion Products	Hydrocarbon Evaporation	Other
Tailpipe Running Exhaust	Diurnal	A/C Refrigerant Leakage
Tailpipe Start Exhaust	Hot Soak	Brake Wear
Crankcase	Resting Loss	Tire Wear
	Running Loss	
	Vehicle Refueling	
	Fuel Leakage	
	Offgassing	

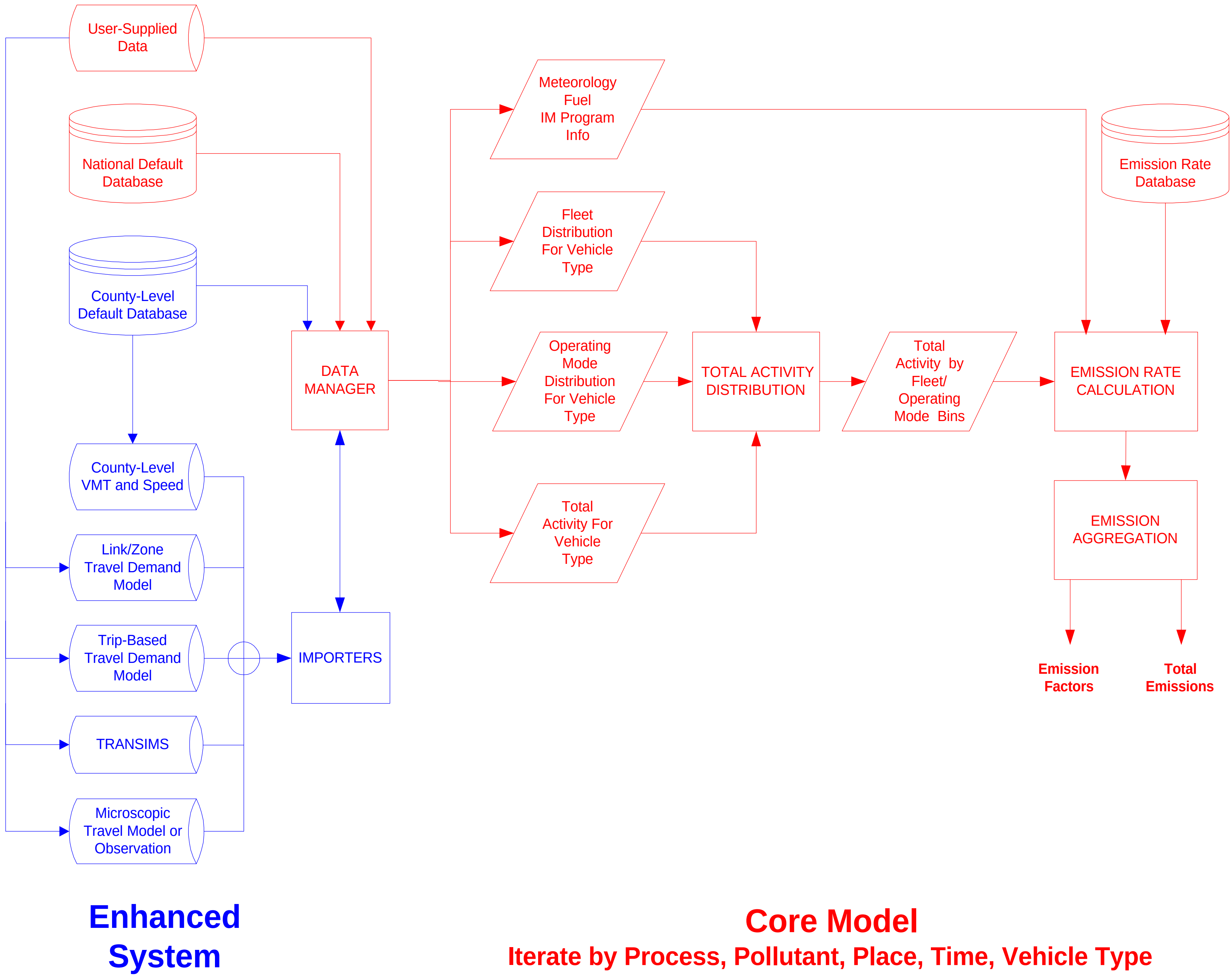
For now, these processes are being defined the same as they were in MOBILE6, except for offgassing, which has been added to include hydrocarbons escaping from car materials such as upholstery. These emission processes are generally associated with different fleet bins and operating modes, and they may also produce different pollutants. Therefore, each emission process is generally handled separately from the others, using common data when appropriate. From a design perspective, this separation creates several submodels within the model. For example, running exhaust emissions are affected by a different set of fleet and activity characteristics than are diurnal evaporative emissions.

In order to meet the MOVES design goals of consistency, updateability and flexibility, a generic modeling approach is being developed that can be applied regardless of analysis scale, emission source, emission process, or pollutant. The common elements of mobile source emission estimation are the following: for a given place and time, there are a certain number of vehicles engaged in a certain activity (including parked) and generating emissions as a result of that activity. Calculating total emissions for that place and time therefore requires, for each emission process, 1) calculating total activity, 2) distributing total activity across the fleet bins and operating modes which differentiate emissions, 3) calculating emission rates for each fleet bin and operating mode; and 4) aggregating emissions across these modes using the fleet bin and operating mode distribution from Step (2).

For generality across all vehicle and equipment types and all emission processes, we propose to characterize total activity by vehicle-time, i.e. vehicle hours operating (VHO) or vehicle hours parked (VHP). Vehicle-time is the product of the population of vehicles/equipment and the analysis time span. Vehicle-time is an attractive way of characterizing activity, because it is common to all emission processes and operating modes. For on-road vehicles, vehicle-time is more broadly applicable than the more conventional Vehicle Miles Traveled (VMT), since diurnal or idle emissions are produced when a vehicle is not moving. For non-transportation equipment, such as bulldozers and cranes, VHO and VHP can be applied as with on-road sources, while VMT cannot. It is important to note, however, that this use of vehicle-time mainly applies to the calculation of emissions within MOVES and does not preclude the use of VMT to express the activity of on-highway vehicles, since VHO and VMT are easily inter-convertible if average speed in known (VHO equals VMT divided by average speed). The model is being planned to accept a wide variety of inputs (see discussion of "importers" below), including VMT, and to produce a wide variety of outputs, including emission factors in grams/mile.

There are two basic components of the MOVES design that have evolved from the generic framework: the "core" model and the "enhanced modeling system", as shown in Figure 2. The core model would accept inputs of a) total activity, b) fleet distributions, c) operating mode distributions, and d) information on meteorology, fuel, and control program. Its outputs would be emission factors and total emissions. For on-road vehicles, this core system is envisioned to be similar in scope and

Figure 2. Generic Data Flow Diagram for MOVES Conceptual Design



functionality to MOBILE6, although it would enable the calculation of total emissions as well as emission factors.

At the heart of the core model is the emission calculation function. It is envisioned that a large part of this function will be a direct database lookup of emission rates that have been processed from raw data using a standardized analysis procedure. This procedure could be developed into a “data crank” software module implementing the “Update Model” use case. The raw data will not be within MOVES, but will be accessible to users and researchers.

The “enhanced modeling system” would use the core model to address many of the use cases discussed in Section 2. For example, macroscale inventory generation would operate the core model in conjunction with a county-level database of fleet and activity information. Interfacing with mesoscopic or microscopic transportation models would require additional software modules (“importers”) to convert activity information from these models into a form the core model could use. Uncertainty analysis using Monte Carlo simulation would require a module that would iterate the core model many times, while populating the input parameters with random samples from the distributions of their means, and then analyze the combined outputs to produce uncertainty estimates.

Fundamental to the enhanced modeling system is the concept of “importers”, which would convert data from a multitude of sources to the standard input form acceptable to the core model. For each emission process, the core model would be developed to use a standard input form for total activity and operating mode distributions regardless of analysis scale or the ultimate source of that information. It is envisioned that we would develop some importers for MOVES to support essential use cases, while some importers would be developed by parties other than EPA, using standard interfaces in MOVES.

One importer EPA will be developing as part of the enhanced modeling system is the Macroscale Importer, which will be necessary for developing the county-level national inventory implementation. For the running exhaust process, the Macroscale Importer would take input of VMT and average speed by HPMS roadway class and convert it to total activity (VHO) and operating mode distributions for use in the core model. As a default, we are considering using the county-level activity data currently used in the development of EPA’s National Emission Inventory (NEI) for on-road mobile sources. The NEI database allocates VMT determined from state-level data on annual average daily traffic and road length from the Highway Performance Monitoring System (HPMS) to the county level using U.S. Census data categories urban, rural, and small urban. The NEI database uses a set of standard average speeds for each of the 12 HPMS roadway types by vehicle class.

The importer concept is key to allowing MOVES to estimate emissions at the mesoscale and microscale level. Mesoscale analysis will require similar information used in macroscale analysis, but for individual roadways and spatial areas rather than aggregated roadway classes and counties. Specifically, importers could be developed to take link-based volume and speed from transportation models and convert them to VHO by operating mode for that roadway link, or to take trip origins by Transportation Analysis Zone (TAZ) and convert them to number of starts per hour distributed by soak time. Diurnal emissions will use Vehicle Hours Parked (VHP), also distributed by soak time. Likewise, for microscale analysis, importers could be developed to take vehicle trajectory information from direct observation or microscopic transportation models and convert it to VHO by operating mode. We envision that once the standard interface with the core model is established, parties other than EPA could develop importers for specific applications, including traditional travel demand models, advanced modeling systems such as TRANSIMS, and microscopic transportation models.

A database of national default and county-level information will enable MOVES to calculate county-level inventories without additional user data. User-supplied information could override these defaults if desired. There could be considerable "mixing and matching" of these input data sources across the different analysis scales. Therefore, a Data Manager will manage the many potential sources of input to the core model, ranging from county-level and national defaults to user-supplied data to the output of travel models.

An important element of MOVES will be the quantification, where possible, of model uncertainty and variability. We propose to characterize emission rates with a mean value, a distribution form, and distribution parameters to allow the development of a utility in MOVES which would apply Monte Carlo analysis to generate uncertainty estimates of model results. In addition to facilitating the calculation of model uncertainty, defining the emission distributions in conjunction with the emission rates would allow a change in the method for accounting for "high" and "normal" emitters from a discrete distribution approach (as in MOBILE6) to a continuous distribution approach. For a given fleet bin and operating mode, the distribution would reflect the spread of emissions of all vehicles, "high" and "normal". The effects of in-use control programs such as I/M would then be modeled by adjusting the parameters of these distributions.

4 ANALYSIS OF EMISSION DATA

A key challenge to estimating emissions at multiple scales is the desire for consistent emission rates across analysis scales. Without this consistency, we are concerned that analysis at the different scales will produce fundamentally different results of uneven quality. To address this concern the April 2001 issue paper proposed the concept of an "Emission Rate Estimator" that would produce emission rates consistent across all scales of analysis. The issue paper outlined three possible approaches to developing an emission rate estimator: 1) develop a physical instantaneous emission model which takes microscopic vehicle trajectory information and produces emissions aggregated to the desired level; 2) generate modal emission rates directly by processing a database of instantaneous emissions into modal bins (e.g., acceleration, deceleration, cruise, idle), applying these rates directly for finer scale analyses and aggregating as necessary for macroscale analyses; and 3) link directly to a database of raw instantaneous emission measurements, so that the emission rate estimator would essentially query a database of these raw data.

We have focused on assessing the best method for estimating exhaust emissions in MOVES based on the three concepts outlined above, and on how using data collected by on-board emission measurement could be used in developing emission rates for MOVES. To evaluate both issues, we devised the "On-Board Emission Analysis Shootout". This effort supplied on-board emission data gathered on 12 light-duty vehicles, 12 transit buses and 3 nonroad pieces of equipment to three contractors determined through a competitive selection process, and asked them to develop from these data a model which could predict total HC, CO, CO_2 and NO_x emissions for a period of vehicle operation. The contractors were then required to predict total emissions for individual trips on an independent sample of light-duty vehicles and buses, and one hour of additional operating on the same nonroad pieces of equipment,[4] and compare the results to the actual emissions. The purpose of the validation portion of the shootout was to provide an initial sense for the promise of different approaches to using on-board emission data in MOVES. An equally important factor in assessing the shootout emission estimation methodologies for MOVES was an evaluation of feasibility, summed up by the following questions: Can the method be applied consistently across the analysis scales? Can it be easily updated as new data becomes available? Can it adapt data from a number of sources, including possibly laboratory second-by-second data, bag data, inspection/maintenance program data and remote sensing data? Would a software implementation of the approach be efficient?

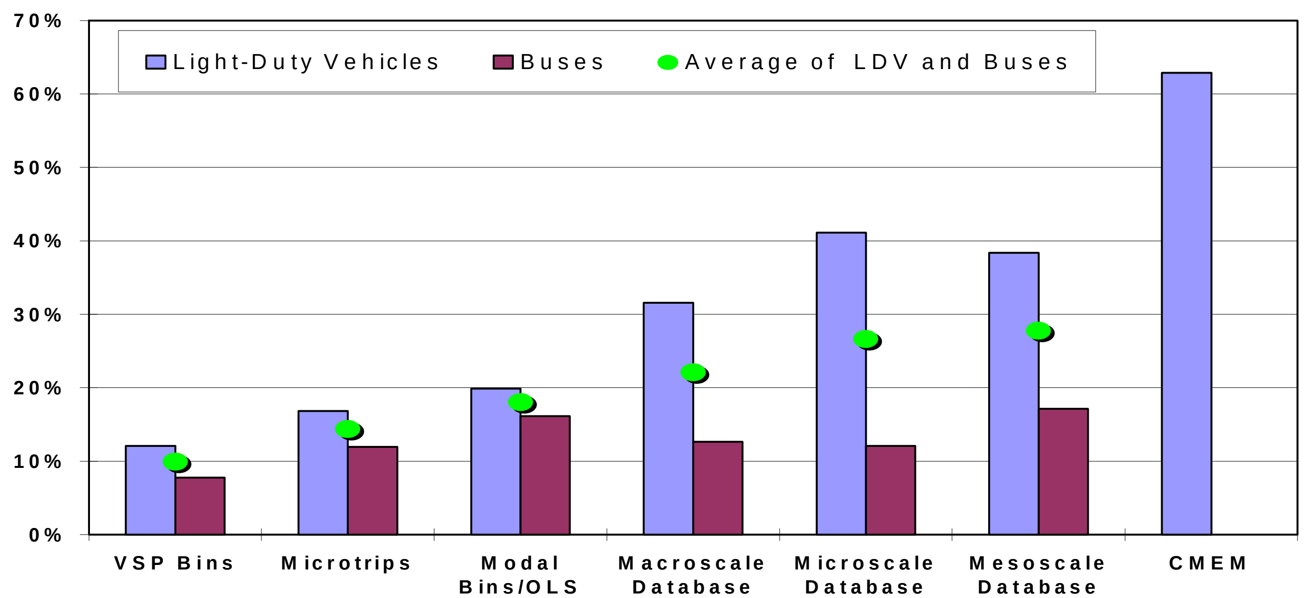
The three contractors who participated in the shootout were North Carolina State University

(NCSU),[5] University of California at Riverside (UCR),[6] and Environ Corporation.[7] NCSU pursued a modal "binning" approach similar to Approach 2 outlined above, in which they defined operating bins based on speed and power, and refined the estimates within each modal bin using regression analysis. UCR pursued a database approach similar to Approach 3, deriving separate emissions for macroscale, mesoscale and microscale based on a database lookup of individual vehicle and trip results. Environ based their approach on a calculation of vehicle specific power (power per unit mass, or VSP), aggregating results over "microtrips" (20 or more seconds of operation, defined by endpoints of stable operation). In addition to these participants, OTAQ staff pursued a variation of Approach 2 based on the binning of VSP on a second-by-second basis using published equations for VSP.[8, 9]

Although Approach 1 (physical microscale emissions model) was not directly represented in the shootout, UC Riverside ran its Comprehensive Modal Emission Model (CMEM)[10], a physical microscale emissions model, over the light-duty vehicle validation dataset. CMEM was developed using laboratory data and was not calibrated using the same on-road emissions data as the other shootout models, so the comparison with the shootout models is not fully equal. However, the shootout models and CMEM are similar in that they predict emissions for a given trip based on independent vehicle trajectory, grade, soak time and vehicle information. The CMEM results, therefore, provide some insight into the viability of Approach 1 for estimating emissions in MOVES.

Summary results for the on-road portion of the shootout are presented in Figure 3. Because the ultimate goal of MOVES will be to predict emissions for a given place and time from multiple vehicles (including microscale analysis, which we propose to define as 15 minutes at a specific location), comparisons are made based on the average of the validation trip dataset.

Figure 3. On-road shootout results summary for all pollutants. Trip predicted and measured emissions were averaged for each pollutant (HC, CO2, CO, NOx) in each on-road category (LDV, Buses). Absolute percent differences between predicted and measured trip averages were then averaged over all pollutants.



An additional evaluation of the approaches based on our feasibility criteria is shown in Table 2. We are grouping the shootout approaches and CMEM according to the three methods outlined initially, except Environ's microtrip approach, which falls outside these classifications.

Table 2. Evaluation of approaches to emission rate estimation from on-board data.				
Feasibility Criteria	**Physical Model**	**Modal Binning**	**Database**	**Microtrip**
Consistent Across Scales?	X	X		
Easily Updated?		X	X	X
Can Incorporate Many Data Sources?		X	X	
Software Efficiency?	X	X		X

When model performance and feasibility are considered, our preliminary assessment is that the modal binning approach appears to be the most attractive. It is simple, data-driven, can use data from multiple sources, and is easy to update with new data. In particular, vehicle-specific power, which combines speed, acceleration, road grade and road load, appears to be an excellent metric for characterizing vehicle exhaust emissions. We therefore plan to pursue additional proof-of-concept work looking specifically at the modal binning approach on a wide variety of data sources, including laboratory second-by-second data, bag data, inspection/maintenance program data and remote sensing data, using vehicle specific power to define modal bins.

5 SOFTWARE DESIGN AND DEVELOPMENT

One of this project's principal goals is to implement MOVES with high-quality software, using the most appropriate, state-of-the-art software engineering techniques. This should enable us to obtain accurate, maintainable, extendable software as quickly as possible, providing users with a well-documented, easy-to-use model that can be readily updated as improved data and methods become available. MOVES should be "easy-to-use", which for this project means (among other things) accepting ASCII text input files similar to those of MOBILE6, having both batch and GUI user interfaces, operating on the computers that most people are likely to have, and not requiring users to purchase software licenses. We also want the software itself to be modular; components should be usable individually as well as in combination; and it should be possible to replace model components with others which conform to the same specification. These software quality objectives are discussed in greater detail in the April 2001 issue paper and have not changed, although we continue to learn about how to best achieve them.

We expect that the Multi-media Integrated Modeling System (MIMS) being developed by EPA-ORD will be of significant benefit to this project. MIMS is a framework being implemented with state-of-the-art methods by EPA-ORD to facilitate the integration and interaction of environmental models.[11] The MIMS project is helping to inspire and inform the design and development of MOVES and is likely to provide useful elements to its software development.

Perhaps of most general significance, we have embraced the practice of iterative software design and development. This means that the usual development life cycle of design, programming, and testing—leading to eventual product release and use—will be repeated many times, allowing EPA to gain expertise and for MOVES to develop incrementally. This will allow us to work closely with customers, for requirements to change, to get rapid feedback, and to produce frequent internal and external product versions.

We have also undertaken two preliminary efforts towards producing an initial object-oriented software design for MOVES. Object-oriented design allows the form of the design solution to correspond more directly to the subject matter being modeled and as a result to be more easily understood and verified than traditional software designs. The first effort involved EPA staff working with a consultant from Cimulus, Inc., a software development services contractor located in Ann Arbor, MI.[12] This effort concentrated on designing the vehicle activity distribution and emission factor calculation functions of the "core" system. A subsequent effort was performed under contract with MCNC, a software development firm which has been heavily involved in the development of MIMS. This produced a top-level design for the full "enhanced" system, partially within the MIMS framework.[3] This effort identified a number of potentially useful MIMS features and components and what a set of GUI interfaces for MOVES might look like.

These design efforts have reinforced our awareness that it will not be possible to produce a complete software design until we determine in sufficient detail what vehicle operating modes will be used and how they will determine and structure the underlying emission rates. Both efforts have helped identify areas where decisions need to be made about our emission calculation methods. At the current time therefore we consider both these designs to be internal products, and, consistent with our iterative approach, we are attempting to learn more and begin another design iteration, which will produce a more complete design framework for MOVES and a more detailed design for our first working product, a macro-scale model to estimate greenhouse gas emissions.

We have made a preliminary decision to program MOVES with the Java programming language as defined by SUN's Java System Development Kit (SDK). Java is a modern, widely used, object-oriented, programming language. It offers a high degree of platform independence, which is one of our objectives. Java comes with a set of associated tools, such as Javadoc, which lead to relatively uniform coding and documentation practices. Using Java also maximizes our ability to take advantage of MIMS. An initial example of this is that we have made a preliminary decision to adopt the MIMS Java Programming Standard. Our one concern with the choice of Java is execution speed performance. We realize that it may eventually be necessary, if portions of MOVES written in Java prove to be performance bottlenecks, to convert them to another programming language, such as C++.

We plan to develop automated unit tests for each MOVES software module, and to maintain and extend this test suite as an integral part of the software development process. We have made a preliminary decision to employ Junit, a widely-used extension to the Java SDK for this function.

Several more components will also be needed to complete an initial software development environment. One is a structured query language (SQL)-based database management system (DBMS) that can be used with Java to create and retrieve data from an underlying structure of data tables that will support MOVES. We are in the process of evaluating several database management software products for this purpose. Another necessary component, since we plan to program and test portions of MOVES ourselves, as well has to have multiple contractors work on the project, is establishing a place where the official source code for the system will be maintained in a controlled fashion and be accessible to developers. We plan to evaluate Concurrent Versions System (CVS, an open source version control system), SourceSafe (a Microsoft product), and other tools for this purpose as well as the feasibility of obtaining an internet-accessible service for MOVES source code.

6 MODEL QUALITY

Model quality planning provides several important safeguards in the development of the model, including systematic planning, standardized operating procedures, peer review of model theory and mathematics, and clear documentation of assumptions, data requirements, and parameterization of theory. These safeguards are recommended by the NRC report, are the focus of emerging EPA guidelines for model quality, and help in ensuring that both decision-makers and the user community are aware of the strengths, limitations, and future plans for the model.

As part of the quality planning process, OTAQ is currently drafting a quality assurance project plan (QAPP) for publication in Fall 2002. The QAPP will serve as an easy reference for the model development team, the user community, and other interested parties, to model development plans, model team organization and administration, software and hardware requirements, data management plans, data quality goals, strategies for future data collection, and plans for scientific peer review. The QAPP is currently being developed in accordance with draft *Guidance for Quality Assurance Project Plans for Modeling*.[13] The MOVES QAPP focuses on three areas: 1) model quality, objectives, and assessments, 2) establishment of consistent standards for model calibration, testing, validation, performance checks, and documentation, and 3) stakeholder and scientific peer review.

Because of the importance of mobile emissions to decision-makers, MOVES should produce emissions estimates that are verifiably accurate, precise, and unbiased. Furthermore, it is important to identify criteria for model performance that help in future data collection efforts. In consultation with EPA management and the stakeholder community, OTAQ is developing data quality objectives for model outputs.

One of the use cases identified as high priority and discussed at length in the NRC report is the ability of the model to produce estimates of uncertainty, variability, and sensitivity. The ability to estimate model uncertainty and variability will assist in future model development and data collection. Sensitivity analysis will help model users understand the importance of various model inputs.

Another quality objective is model validation, which involves the comparison of predicted values to values collected in use, including emission rates and total predicted emissions. Model inputs that are candidates for validation against in-use data include vehicle activity, distribution of vehicle emitter types (i.e. "high emitter" frequency), frequency of air conditioning use, nonroad engine population, and geographic distribution of all sources. The QAPP proposes data collection concurrent with model development to allow for validation. The QAPP will outline objectives for model accuracy and precision and means for assessing them.

The QAPP will also document standard operating procedures (SOPs), which are currently under development. Among the SOPs to be developed are those for data collection, data management, model quality assessments, software development (coding), documentation, and version control (documents and computer code). Because the MOVES development process is envisioned as one of regular iteration, the SOPs being developed will include appropriate treatment of new model versions.

MOVES credibility depends on adequate scientific peer review and stakeholder involvement in model development planning. Plans for MOVES have regularly been submitted for review by the Modeling Workgroup of the MSTRS of the CAASAC. MOVES will undergo scientific peer review consistent with the EPA *Peer Review Handbook*.[14] The QAPP envisions the convocation of an expert review panel and the publication of model theory, quality assessments, and initial implementation in the scientific peer reviewed literature.

7 IMPLEMENTATION PLAN AND TIME LINE

An implementation plan for MOVES has been developed based on two objectives: the desire for an iterative approach to developing and releasing the model and the desire for model stability given the recent release of MOBILE6. To meet these objectives we are currently moving ahead with a macroscale greenhouse gas implementation for on-road sources, by Fall 2003. This implementation would support development of national inventories and projections at the county-level for CO_2, N_2O, CH_4 and air conditioning refrigerants. Choosing a macroscale greenhouse gas model as the first implementation of MOVES allows us to start with a small scope relative to all of the considerations that go into modeling of ozone-precursor and criteria pollutants. For example, the model will not need to address evaporative emissions or implement finer scale emission analysis.

A greenhouse gas implementation of MOVES will serve important needs within EPA and in the model user community. A comprehensive model that allows bottom-up estimation of greenhouse gas emissions from on-road sources is currently not available, and the development of such a model is recommended by Intergovernmental Panel on Climate Change guidelines.[15] It will also give the broader user community an opportunity to work with MOVES while the full-scale version of the model is developed.

The next implementation of MOVES is planned for Fall 2005, and would add HC, CO, NOx, SOx, PM, NH_3, and air toxics for on-road sources and would allow the estimation of emissions at multiple scales. This implementation would replace the current MOBILE6 model. The two years between implementations would be focused on the development of emission algorithms for these pollutants, since the software aspects of the model will have been significantly developed for the greenhouse gas implementation.

In order to manage the scope of the project, new estimates of off-road emissions would not be integrated into MOVES until after the on-road implementations were developed. Prior to the development of new estimates for off-road emissions, we are considering integrating the NONROAD model into the MOVES framework in conjunction with the on-road releases. This would allow the estimation of emissions from all mobile sources within one modeling system, an important objective of MOVES.

8 CONCLUSIONS

Progress on EPA's new mobile source emission model has centered achieving three objectives laid out in the April 2001 issue paper: 1) increase the scope and flexibility of the model to address the growing range of mobile source modeling needs in a comprehensive manner, 2) improve the science of the model, and 3) improve the software design of the model. By focusing on these objectives, a fourth objective of addressing the key recommendations of the National Research Council is also being met. The universe of potential model applications has been identified through a “use case” analysis. A conceptual design for MOVES has been developed to address these use cases, consisting of a core emission rate estimator and enhanced modeling system, which employs “importers” to enable the use of data from a wide variety of sources at the macroscale, mesoscale and microscale levels. The data used in the model will be accessible to users and researchers and will be configured to allow the model to be readily updated as new data become available. Initial software considerations include pursuing an object-oriented design using Java and elements of MIMS. Emission estimation approaches have been assessed, with a modal binning approach identified as the most promising in terms of consistency, feasibility, accuracy, and model performance. Model quality will be assured by the development of a Quality Assurance Project Plan, following EPA guidelines and including model quality objectives, standard operating procedures, and peer review. Implementation will begin with a greenhouse gas model, for its relative simplicity, in Fall 2003. The full range of pollutants currently contained in MOBILE6 will be added by Fall 2005.

DISCLAIMER

References to commercial and non-commercial software and to consulting firms should not be taken as an endorsement by EPA. The primary purpose in presenting this paper is to facilitate the exchange of technical information and to inform the scientific and model user communities of ongoing work within EPA. What we have presented is a plan. It is subject to change as we proceed.

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