February 3, 2003

To: Environmental Protection Agency
2000 Traverwood Drive
Ann Arbor, MI 48105

Attention: Robert J. Johnson
Project Officer, OTAQ/ASD/ATC

From: Patrick M. Merritt
Department of Emissions Research
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

Subject: Final Report for Work Assignment 1-5, EPA Contract 68-C-02-022, under SwRI Project 08.06129.05

Contract Title: "Testing and Analytical Support for Regulation of Motor Vehicles, Engines, Fuels, and Fuel Additives"

Assignment Title: "Independent Peer Review of the MOVES Design and Emissions Analysis Plans"

I. INTRODUCTION

On December 2, 2002, Southwest Research Institute submitted a revised Work Plan for Work Assignment 1-5, "Independent Peer Review of the MOVES Design and Emissions Analysis Plans" in response to the EPA Statement of Work (included in Appendix A). The Work Plan was approved by EPA on December 12, 2002.

Our first responsibility was to identify three qualified individuals to participate in the peer review panel of the "MOVES Design and Emissions Analysis Plan." In the identification of potential reviewers, SwRI was to consider qualifications, availability, and conflicts of interest that would preclude an independent review, as required by the EPA *Peer Review Handbook*. In addition, EPA expects to have additional, related documents for peer review in the coming year. Willingness and availability of the candidate reviewers for additional tasks were also considered.

For this first document, reviewers with specific expertise were desired. Individuals with expertise in the following fields were sought:

- mobile source research and modeling, including expertise in the physical process of generating and controlling vehicle emissions,
- application or analysis of current mobile source emissions models for either regulatory purposes and/or policy evaluation, and
- the link between mobile source emission modeling and transportation modeling and planning.

After approval by EPA of the three individuals nominated by SwRI, we were to establish consultancy contracts with them to conduct an independent, peer review of the "MOVES Design and Emissions Analysis Plan." Within eight weeks of EPA's approval of the members of the review panel, SwRI was to provide a summary report, along with their complete reviews, to EPA as the final deliverable under this Work Assignment.

II. DISCUSSION

The membership of the Transportation Research Board Air Quality Committee and of the National Research Council Review Panel was used as a resource for potential reviewers. The credentials of numerous members of these two panels were reviewed by locating their resumes or home pages on their respective internet sites. Thirteen individuals were contacted to ascertain their interest, availability, primary research areas, and other factors which would qualify them to conduct a peer review of the MOVES model. Of these thirteen, five were selected by SwRI and submitted to EPA as possible candidates. All five were approved by EPA as acceptable candidates on December 16, 2002. From those five, SwRI initiated procedures to secure consultancy contracts with three of them. Those three individuals included the following:

- Dr. Marc Ross, Professor Emeritus, University of Michigan
- Mr. Christopher Saricks, Transportation Systems Analyst, Argonne National Laboratory
- Dr. Armistead Russell, Professor, Georgia Institute of Technology

On December 23, 2002, the SwRI Legal Office ruled that a contract clause required by Mr. Saricks' employer was in conflict with SwRI's contract with EPA. Several days were spent trying to resolve the issue, the winter holiday period causing even further delays. Ultimately, and with EPA's approval, it was decided to cease contract negotiations with Mr. Saricks and attempt to replace him with Mr. Michael Replogle, Transportation Director, Environmental Defense. On January 6, 2003, we initiated contracting procedures with Mr. Replogle.

The complete reviews submitted by Messrs. Ross, Replogle, and Russell are attached to this document as Appendices B, C, and D, respectively. Each reviewer has adequately addressed the items presented in the "Charge to Reviewers" and has provided additional commentary and specific recommendations as well.

As part of the work assignment, SwRI was to summarize the reviewers' comments, organized by the questions posed in the "Charge to Reviewers" document. That summary is as follows:

1. *Do the "use cases" presented in the document appropriately capture the needs of the mobile source emission modelers?*

   The consensus appears to be that the model design is well thought out and provides a sufficiently broad range of cases. Desire for additional capability was expressed, to include the following:

   - Addition of a capability for "environmental justice" evaluation, under "local inventory development" and "hot-spot and project level analysis" was requested.

   - Greater accommodation of health effects and toxicity studies, with associated fine temporal and spatial scale data was desired.

   - Additional discussion was requested in "Section 2. Use Cases," to explain the kinds of strategies and policy issues which MOVES is designed to address, and to elaborate policy evaluation capability and model interactions. Addition of capability to evaluate "traffic calming" strategies, modification of vehicle choice decisions for individual trips, and inclusion of a provision for "congestion pricing" was also requested. Details on the specific recommendations are found in the individual review documents.

2. *Does the proposed model design satisfy these use cases as suggested by EPA? A specific issue for the panel to address as part of this question is whether the proposed approach for handling multi-scale emission estimation (including the defined scope and macroscale, mesoscale and microscale) is adequate.*

   The consensus appears to be that in general, the model design satisfies the proposed use cases. Some of the issues were as follows:

- There was some concern expressed that it may not interact with SMOKE adequately, and that it would be useful to have it link to the programs TransCAD, Emme2, TP+, and PAVE.

- Concern was also expressed that good default information is available to relatively modest users at the meso scale.

- In addition, there was desire for data visualization capability, perhaps by linking output with programs like PAVE, and for enhancement of the way in which cold starts and high-emitters are handled.

3. *Does the proposed model design allow for a range of input data options that is sufficiently broad to not impose an undue burden on "low end" users while allowing sufficient flexibility for highly specific applications?*

    The consensus appears to be that the model design would allow for a sufficiently broad range of data input options, and will satisfy low end users. However, one reviewer stated that the potential complexity of the GUI may lead regular users and sophisticated programmers to want to bypass the interface entirely, allowing them to use models in a stand-alone fashion. Linking to other programs, as stated above, would be useful.

4. *The panel should review the mathematical formulation presented in Section 7 of the plan in detail and provide comment on the following issues: Do the formulations for the total activity generators and operating mode distribution generators adequately fulfill the stated purpose of these generators? Are they mathematically sound? Are there alternative formulations which should be considered? Are the proposed data sources discussed as possible inputs for parameters, both at the default and local levels, readily obtainable and the best available? Are there alternative data sources not presented in the plan which should be considered? Are the levels of aggregation proposed in each step (i.e., what the inputs and outputs can vary by) appropriate given available data and the needs of users? Are there specific steps which are either over-specified (more disaggregation than is necessary) or not disaggregated enough to account for needs of users and real emission variability*?

    The reviewers are generally satisfied that the mathematical generators are sound and for the most part, fulfill their stated purposes. The use of multi-scale estimation architecture appears valid and is a desirable feature. There was little overlap in the specific comments of the reviewers. However, some specific comments and recommendations regarding Section 7 are as follows:

    - More information on the MEASURE framework for more disaggregate meso-scale analysis is desired.

- It would be valuable to develop policy-sensitive sketch modeling tools in the steps TAG-4, -5, and -6 to allow the model to reflect alternative policy scenarios.

- Consider an alternative approach to the historical trends and economic projections method described on page 40. (See Replogle for a lengthy explanation)

- Include a feature which models induced traffic impacts and changes to traffic congestion and delay, to facilitate conversion to source hours operating (SHO) from vehicle miles traveled (VMT).

- Include a facility for sketch models to represent policies that influence time-of-day-of-travel.

- Avoid static assumptions in incorporating average vehicle speeds.

- It would be useful for source hours parked (SHP) to be derived from a parking inventory database.

- The ability to conduct fuel-based emissions estimates would be useful.

- Use of bins with regard to source-specific power could lead to discontinuities that likely do not exist in fleet emissions distributions, given the wide range of vehicles. There was also objection to the use of bins for information like mileage: linear fits to data are preferred.

- The use of Monte Carlo methods for conducting uncertainty analysis can be time consuming. The use of direct methods is faster and identifies sensitivities squarely. If Monte Carlo methods are used, add the ability to conduct regression analysis to identify the dependencies and global sensitivities.

- It would be very useful to be able to archive calculations to cut down on the need to re-run the entire calculation.

- There is concern that information on old vehicles will be inaccurate and location dependent. Also, with regards to the emissions rates of older vehicles, MOVES appears to be limited by the need to develop data directly. It would not be adequate to extrapolate data on younger vehicles.

III. CLOSURE

Preparation of a consensus report for reviews from three diverse viewpoints has been a challenge. It is hoped that this summary is useful. As the review reports are concise documents, the plan authors are encouraged to rely on them directly for increased clarity and for the context in which the criticisms were put forth.

It has been our pleasure to assist EPA in procuring these peer reviews of the "MOVES Design and Emissions Analysis Plan." With this submission, the requirements of Work Assignment 1-5 are fulfilled.

Should any you have any comments or questions, please contact Mr. Patrick Merritt (telephone 210/522-5422, e-mail pmerritt@swri.org) or Dr. Lawrence R. Smith (telephone 210/522-2977, e-mail lsmith@swri.org). Thank you for this opportunity to be of service.

Prepared by:

Patrick M. Merritt
Senior Research Scientist
Department of Emissions Research
Automotive Products and Emissions
Research Division

Approved by:

Bruce B. Bykowski
Director
Department of Emissions Research
Automotive Products and Emission
Research Division

Reviewed by:

Lawrence R. Smith
Manager, Light-Duty and Unregulated Emissions
Department of Emissions Research
Automotive Products and Emissions
Research Division

c: Norm Pattenaude, SwRI Contracts

APPENDIX A

STATEMENT OF WORK
WORK ASSIGNMENT 1-5, EPA CONTRACT 68-C-02-022

APPENDIX B

INDEPENDENT REVIEW OF
"MOVES DESIGN AND EMISSIONS ANALYSIS PLAN"

BY

MARC ROSS
PROFESSOR EMERITUS
UNIVERSITY OF MICHIGAN - ANN ARBOR

REVIEW OF "DRAFT DESIGN & IMPLEMENTATION PLAN....(MOVES)"
Marc Ross, Physics Dept, University of Michigan, mhross@umich.edu

I will comment on the estimation of emissions from automobiles (cars and light trucks).

I. DEALING WITH IMPORTANT ISSUES
My focus is on serving important needs adequately. MOVES as described is remarkably flexible and, I judge, would be relatively easy to implement in many of the wide range of Use Cases. So it's an impressive effort (albeit I don't understand some parts). I am concerned that the framework and/or default data for convenient and accurate analysis may not be adequate for some important activities/sources. The design for important activity/sources needs to be developed with more care than for unimportant ones, given that there will be limitations on people's time understanding MOVES, preparing inputs and on computer time. I may not be right identifying these most important cases, but the general point may still apply. I believe one must not sacrifice adequate accuracy in really important situations on the altar of a system with uniform applicability. Two of my concerns are cold starts and high emitters.

Cold starts: The history of emission factors in the 1990s shows that cold start emissions of normal emitters declined slowly if at all, while running emissions of normal emitters declined sharply, and this was for good engineering reasons. In my opinion, characteristics of normal emitters that are more than 15 or 20 years old can be sharply approximated. Those vehicles are disappearing from use, while cold start emissions of later model vehicles may need to be analyzed in detail. For example soak time and its impact on cold starts (Table 7-4) may need emphasis. The impact of ambient conditions may also need emphasis. The typical handling of starts by drivers may be dependent on cold weather. If these effects are important, the structure, the default data and instructions to users should illustrate the fact.

High emitters: The plan for high emitters is not described in any detail. But the implication seems to be that this is a monolithic category (e.g. Table 7-2). However, a rich category is needed. What kind of high emitter (e.g. runs rich, runs lean, catalyst failure and misfire, as discussed in Ross & Wenzel, SAE 981414)? Do the kind, incidence and scale of emissions depend on location? It seems likely that they do. For example, surveys show emissions to be higher in Colorado than in other states which also have I/M and remote sensing programs. (That may not be surprising given that there is a lot of mountain driving; and that may strain the capabilities of automotive propulsion and control systems.) It is not obvious to me in reading the Draft Design Plan whether location dependence is expected for high emitters. As far as I know, there isn't a satisfactory method for determining the incidence and characteristics of high emitters. MOVES should provide help for users who try to develop adequate and economical approaches to this challenge.

An Exercise in Using the Plan
Let me discuss a set of issues in the context of "use case". Assume that a domain like an Air Quality Management District is troubled by the fact that certain ambient pollution levels

have not declined over recent years even while the emissions by new automobiles, as allowed under regulations, are declining rapidly. (Automobiles means cars and light trucks.) Let me ask: How might MOVES be brought to bear? Is the structure appropriate to the needs and possibilities? (I can only touch the surface.) Let's not consider that non-automotive sources play a major role. The main possibilities may be: 1) Total emission-process activities may be changing for the worse (increasing number of starts, increasing source hours, and activities shifting into more sensitive times of day (sections 3.1.1 & 7.1.2 & 7.1.3?). 2) Operating modes may be changing, in particular the high power component of VSP distributions may be increasing, and perhaps braking events are increasing (sections 3.1.2, & 7.1.3). 3) Sources may be changing, for example the roles of high emitters and/or high mileage vehicles may not be declining even as emissions standards become stricter (3.1.2).

Examining these possibilities, one finds a place for most of them in the MOVES Draft Plan. So far, so good. But I am concerned about the lack of detail in certain cases where the emissions may be important.
1) For total activities, it is quite reasonable for the serious local user to generate them and their patterns of change with the years, and a procedure is presented in the Draft Plan. But the fact that total activity is relatively straightforward to estimate should not mislead one into thinking that activity at a more detailed level is in hand.
2) Operating modes present a serious problem. Surveys of speeds by roadway and time of day, day of week, and season are practical to make, but it would be much more costly to determine the accelerations as they are associated with speed, roadway and time of day, as in driving cycles. Use of "data generators", which I take to mean use of generic data like the facility driving cycles such as obtained in the past by CARB, would be troubling. One needs some assurance that VSP distributions on different roadways do not vary much over different parts of the country and over the years. There is also the likelihood that old high mileage vehicles are driven quite differently than new vehicles of a decade ago, or than today's typical vehicle. MOVES should provide guidance to users on this issue.

On the other hand, the use of generic information for vehicle emissions would be acceptable in my opinion. Thus, for example, one can assume that a mix of normal-emitting non-high-mileage cars of a given model year, have the same emissions rates in different locations. E.g. the emissions depend on VSP but not on locality.

3) Sources are also very difficult. MOVES is designed in the hope there will be no confounding between categories in the system. In spite of that intent, it is hard to avoid confounding where it is hard to "recruit" or observe an unbiased sample of vehicles, perhaps because hard-to-observe vehicles tend to be driven on different roads and at different times than average vehicles. Thus, one may confound the occurrence of high-mileage vehicles with their emission rates (which I take to mean emissions per second power vehicle. (The same difficulty applies even more to high emitters.) In other words the estimate of the number of old high-mileage vehicles is likely to be highly uncertain, because it may not be typical of all automobiles across roadway types or time. And measurement of their emissions is also likely, in a correlated way, to be uncertain. Yet,

policies focusing on old vehicles may be important. Is the proposal (section5?) to use national data in an informed way to create default information? Such an approach would need to be developed with care. Based on detailed investigation, MOVES should provide guidance to users.

II. MISCELLANEOUS ISSUES

The odometer reading of a vehicle is essentially continuous. In MOVES it appears to be decided to put certain source information like mileage in two bins (low and high), along with a cite to the emissions modeling study at UC Riverside. As a participant in that Riverside study I believe we found that binning to provide very little information. Linear fits to the data would have revealed much more with the same data and number of parameters. And this source information might be important. In other cases the binning is satisfactory, if not in my opinion the best choice: For VSP there are many bins, so the procedure is satisfactory; though it makes me unhappy not to look for large emissions in some narrow variable range, related to the onset of enrichment. For high emitters, our knowledge is so limited that, barring a major study with fresh measurements, this yes-no binning may have to be considered satisfactory. I have already remarked that more detail is needed about high emitters in other respects.

MOVES has a lot to it, so I apologize if I have misunderstood. Referring to section 7.1.2, it sounds as if the default information on total activity generation will be from national data; otherwise it's up to the user. I hope this doesn't mean that analyses of emissions by modest users in the SW will in practice tend to be based on the same vehicle age distribution as in the North-Central region. This is important because the fraction of old vehicles varies strongly, and the single most important vehicle characteristic for emissions may well be model year, which in a given calendar year of emissions is determined by vehicle age.

Use of VSP at the instant as the driving variable that determines emissions is acceptable in my opinion. This simply means that the effect of the driving pattern of the recent past on vehicles' emissions is neglected in the average emissions rate.

ADDENDUM TO MY REPORT ON THE MOVES DRAFT PLAN
Peer Review Charge Questions
Marc Ross, Physics Dept, University of Michigan, mhross@umich.edu

1. The use cases seem to me to cover the wide range needed; but I am not active in the field of users, so I am not well informed.
2, 3. One must ask whether the multiscale approach in MOVES, by being all things to all users, seriously shortchanges an important group of users. I am concerned that good and easy-to-use default information, or data generation capability, be available to relatively modest users at the meso-scale (regional, state, large metro-area applications).
4a. The TAG description in section 7.1.2 is similar to an analysis I have done. I am concerned, as alluded to in my report, that information on old vehicles will tend to be inaccurate and location dependent.
4b I don't know a general source for information on MAR at old vehicle age and by region.
4c In addition to older vehicles' activity, I'm concerned about their emission rates (per vehicle).
I discussed this a little in my report. If older vehicles would be a focus of analysis, for exmple because of a special program or of legislation, it would be challenging to do a good analysis using MOVES, unless a special effort were made to develop needed data directly. It would not be adequate to extrapolate data on younger vehicles, or to use national data.

APPENDIX C

INDEPENDENT REVIEW OF
“MOVES DESIGN AND EMISSIONS ANALYSIS PLAN”

BY

MICHAEL REPLOGLE
TRANSPORTATION DIRECTOR
ENVIRONMENTAL DEFENSE

Memorandum

TO: Patrick Merritt

FROM: Michael Replogle

RE: Review of “Draft Design Plan for EPA’s Multi-Scale Motor Vehicle & Equipment Emission System”

DATE: February 1, 2003

I have reviewed the document as requested and offer the following observations.

The outlined design of MOVES is sound in direction and structure. While it will appear to be ambitious to some, key features of the proposed MOVES framework are frankly not just timely, but overdue. The MOVES architecture promises to better address pressing public policy analysis needs than existing MOBILE and NONROAD tools.

Use Cases

Environmental Justice. The “use cases” presented in the document generally identify the broadest classes of needs of mobile source emission modelers. I recommend, however, adding another bullet under “Local inventory development” and under “Hot-spot and project level analysis” for

“* Environmental justice evaluation.” MOVES could be used to produce meso-scale or micro-scale data on PM and air toxics in proximity to various population groups, in responding to issues being raised in various areas under Title VI of the Civil Rights Act. This goes beyond simple hot-spot analysis, because of the need to intersect the data with GIS demographic data elements. This may also have applications for public health programs beyond ordinary air quality planning, such as asthma programs.

Elaborate Policy Evaluation Capability Needs and Model Interactions. Further discussion would be most helpful in the “2. Use Cases” section of this report or in some other follow-up concerning the kinds of strategies and policy issues which MOVES will be designed to readily address. The “Policy Evaluation” cell in Table 2-1 and the “Model Interaction” cell in the same table begin to get at this, but would benefit from more elaboration. Without such elaboration, it is likely that the software framework of MOVES, like the Mobile models in the past, will focus more easily on the traditional “cleaner vehicles and equipment and fuels”, with less documentation and analytic capacity development to easily consider nuanced strategies for “less travel and equipment use and reducing in-use-emissions.” There are several strategies, for example, that fall between the categories of “modifying vehicle operation” and “less travel and vehicle use:”

Traffic calming. For example, MOVES should be capable of reflecting and evaluating both spot and area wide traffic calming strategies, which German research has shown to be very effective in reducing a variety of mobile emissions and fuel use by adjusting the speed and driving style of vehicle operation (see Appendix A for more information). Traffic calming also usually has the effect of making walking and bicycling far more attractive for short and mid-length trips in many communities. The architecture of MOVES should be perfectly suited to capturing these effects, but without specific attention paid to this specific use case - which is relevant for SIP development, conformity, project level analysis, and policy evaluation – analysis of the emissions benefits of traffic calming is likely to be a neglected or not easily accomplished application of the tool. State-of-the-practice regional travel models are seriously deficient in their capacity to represent pedestrian friendliness, network vehicle speeds by time-of-day, or the traffic characteristics of dense gridded street networks which frequently are just left out of the travel models. It would be of value for MOVES to provide a default national framework to do sketch level analysis of these factors, which could be largely built off of Census TIGER file network data. While I have focused this discussion on infrastructure focused traffic calming measures, driver re-education programs for fleet operators, for example, have been shown recently to constitute a different kind of "traffic calming" and to lead to calmer driving styles that produce measurable reduction in fuel use and emissions. New telematics technologies for smart cruise control might provide a third strategic support for widespread "traffic calming" that can affect emissions and vehicle operations. MOVES is being designed with an architecture that could reflect all these things, but will these strategies be kept in mind as potentially valuable "use cases" to help support conformity and SIP development? I hope so.

Modifying motor vehicle choice decisions for individual trips. Car-sharing cooperatives, use-based motor vehicle insurance policies, emission-based VMT fees, employer-provided transit benefits and cash-in-lieu-of-parking benefits and other proposed strategies may influence the choice of which vehicle a household member uses for a given trip, when presented with the option of using a big SUV or a compact hybrid or a small neighborhood electric vehicle. MOVES again should be well suited to capturing these effects, but only if coupled with a vehicle choice model that is typically not a feature in regional travel demand models (although such tools have been developed for the California Air Resources Board). A default national model to do sketch modeling in this area would be of value, especially as the motor vehicle fleet further diversifies with hybrids.

Congestion Pricing. Widespread use of time-of-day-based motorist fees, such as HOT lanes and value-priced tolls on roads, bridges, and tunnels can influence time of motor vehicle use patterns, with a significant impact on emissions. State-of-the-practice regional travel models are seriously deficient in their capacity to represent time-of-day-of-travel. MOVES should establish guidance to encourage improved analysis in this area. A default national model to support sketch modeling of policies related to time-of-day-pricing would be of value.

Multi-Scale Emission Estimation Architecture Appears Sound. The proposed model design appears to satisfy the use cases as suggested by EPA. The proposed approach for handling multi-scale emission estimation (including the defined scope and macroscale, mesoscale and microscale) appears to be adequate, although I suspect it will present some data base programming challenges to make the generalized architecture work effectively at all levels. It seems both plausible and desirable to continue in the proposed direction with this unified architecture, working through the challenges as they become evident through specific applications.

The proposed model design would appear to allow for a range of input data options that is sufficiently broad to not impose an undue burden on “low end”
users while allowing sufficient flexibility for highly specific applications. The challenge will be in default data base assembly and programming to handle a diverse array of application frameworks. But I think this should be doable.

MOVES Emission Processes. The emission processes used by the MOVES model (page 7) appears to cover key elements. However, I question whether it would be of value to add a process for road dust re-entrainment, which can be a significant contributor to particulate matter emissions. These emissions are typically a function of pavement type, weather, and vehicle miles of travel.

Data Flow Design. The data flow design appears to be reasonable. I would urge that a priority be given to the capacity to import data from several regional travel demand modeling packages. Clearly, linking MOVES to the TRANSIMS model will be of value, as noted on page 33. Linking also to TransCAD, Emme2, and TP+ would also make sense.

Mathematical Formulations Appear Sound. I have reviewed the mathematical formulation presented in Section 7 of the plan in detail. The formulations for the total activity generators and operating mode distribution generators generally appear to adequately fulfill the stated purpose of these generators and to be mathematically sound. However, I have a few questions and there is some room for improvement. I offer the following specific comments and questions on this section:

Page 38: I’d like more information about the MEASURE framework developed by Georgia Tech for more disaggregate mesoscale analysis.

Page 39: Table 7-3 on Travel Activity Generator raises question in my mind. I think it would be of great value for MOVES to early on *develop policy-sensitive sketch modeling tools* *in the steps TAG-4, 5, and 6 to allow the model to reflect alternative policy scenarios* that affect future year VMT growth, spatial allocation, vehicle choice, and time-of-day-of-travel.

Page 40: I strongly suggest that the model for growth of vehicle population from base year to analysis year should be based on a national sample enumeration microsimulation model that ages the population and households and then uses discrete choice models to estimate household vehicle acquisition, retention, and disposition, as well as household vehicle choice for different shares of daily vehicle activity. This approach would be more complementary to the MOVES architecture than the proposed crude historical trends and economic projections method proposed on page 40. Prof. Ryuichi Kitamura, a Professor at Kyoto-University who frequently works on US and European advanced travel modeling initiatives, has developed such household microsimulation models for the Netherlands and I believe perhaps also for the California Air Resources Board. This fits as well with the TRANSIMS framework. This same household-based microsimulation framework might be provided by MOVES to support a more robust vehicle activity analysis at the macro, meso and micro levels of tool application. The STEP model developed initially by Greg Harvey and since adapted into the TransCAD software package by Caliper Corporation provides a ready framework for household travel activity microsimulation, similar in some ways to the non-network travel activity portion of TRANSIMS, but running on a PC in Windows.

Page 41: Whether mileage accumulation rates vary with vehicle age warrants some research. I suspect older cars often get driven less – it's certainly the case in my household – so the assumption that there is not any variation across ages is suspect.

Page 42: VMT growth is treated as an external variable rather than being calculated internally. I urge that MOVES provide at least sketch analysis tools to prevent this package from being used almost exclusively to consider vehicle fuels and vehicle technology clean up strategies, to the detriment of considering strategies that influence travel activity and vehicle operations.

Page 43: It is noted that "conversion to SHO from VMT in later steps relies on average speed which varies by roadway type." It would be of value to recognize in MOVES that average speed and VMT are influenced by changes in highway capacity. There are models that can represent these influences – induced traffic impacts and changes to traffic congestion and delay - on a sketch basis at the highest level of aggregation. There are other models that can capture these impacts at the meso or micro level, although many state-of-the-practice regional travel models are insensitive to induced traffic and land use impacts and most micro-scale models ignore these effects. Hence, including such analysis tools in MOVES, rather than stating these are external factors, would be most warranted.

Page 44: "Hourly allocation factors have been developed from driving survey data as part of Mobile 6 to allocate annual VMT to hour by roadway type, use type, and age. It would be of great value to have sketch models here that have the capacity to represent policies that influence time-of-day-of-travel, including expansion of highway capacity in congested corridors (which moves traffic out of the off-peak and into the peak) and congestion pricing (which moves traffic out of the peak and into the off-peak). Use of static time-of-day travel factors for these elements would make it likely that the MOVE model will simply reinforce current inefficient practices, rather than be readily used to explore potentially valuable and cost-effective market incentive strategies.

Page 46: "National defaults for average speed would be developed by instrumented vehicle surveys or speed studies." This might be a first-cut approach in lieu of other data, but like all static assumptions, would be limiting in its responsiveness to proposed strategies that might either curb or fuel traffic growth. A better approach would be to have the MOVES model incorporate a sketch model for evaluating change in average traffic speed by facility type in each county on the basis of more localized data in the national default case, derived perhaps from average congestion measures from HPMS data, planned highway capacity expansion from the Transportation Improvement Program (TIP) and Regional Transportation Plan (RTP) and its effects on both induced sprawl and VMT, a measure of planned transit investment from the TIP/RTP, and projected population growth.

Page 49: It would be useful for Source Hours Parked to be a function of a parking inventory data base, which could be a submodel that estimated parking based on land use activity and density, with a potential for local modification factors. MOVES should encourage local collection of better parking inventories.

Page 50: Refueling allocation factors based on gas station density is a good idea, but I'm not sure where the data for this would come from.

Page 53: Drive cycle data bases might be one place to reflect the impacts of traffic calming strategies discussed elsewhere in my commentary.

Page 54, first line: typo, missing "with" after the word "conjunction".

Page 54: Assuming default value for grade to be zero for VSP determination would appear to be a problem in areas where average topography is hilly or mountainous. Perhaps this needs to be addressed with a distribution of values based on a measure derived from USGS digital line graphs or topo maps. Digital line graphs can be fairly readily transposed into grade data on TIGER and HPMS networks. Perhaps MOVES (or BTS or USGS) could produce a national default data base of roadways with grades?

Page A-5: Include a "select by attribute" and "select by GIS interface"?
Finally, the proposed data sources discussed as possible inputs for parameters , both at the default and local levels, in many cases are readily obtainable, but in others not, or the specification is too general to resolve this question.

I believe the levels of aggregation proposed in each step (i.e. what the inputs and outputs can vary by) seem generally appropriate given available data and the needs of users, although I'm confident that some users will be disheartened by the potential data requirements. However, the provision of a default set of national data which can at least initially fill many of the data gaps that may exist at the mesoscale or microscale analysis level would seem to address this concern, at least to my satisfaction.

With the concerns expressed above, I think the model otherwise appears to be reasonably well specified. Clearly, as it moves towards fuller development, additional specifications will necessarily have to be fleshed out. While the heart of the design is well articulated in this draft design, not every piece of the data relationships has been fully articulated in this design. I could go on about this, but time does not permit.

I would be happy to discuss these thoughts in more detail with you or other members of the Peer Review or MOVES team.

Attachment A:
Illustration of Selected Issues to Which MOVES Model Might Be Sensitized

Traffic Calming. Traffic calming is a very important means of improving pedestrian and bicycle friendliness, by shifting the management of street space to favor alternatives to the automobile while not barring car traffic. This strategy encompasses a wide range of techniques for slowing down motor vehicle traffic in residential or commercial areas to provide an environment more supportive of walking and bicycling and safer for children, the elderly, and others. Traffic calming schemes may involve a combination of many measures, which are most readily incorporated at low or no extra cost when streets are periodically reconstructed or undergo major repairs:

? **reducing speed limits** on streets to 20 mph or less, reinforced with physical changes in street geometry that encourage drivers to move gently and carefully, rather than rushing at maximum speed down the street.

? **narrowing roadways** along their length or at selected points in mid-block or at intersections.

? **introducing a curvilinear element to formerly straight streets** to reduce sight distances and force speed reductions and greater care in driving, through the use of alternating side of street parking spaces, the planting of trees in streets, and the placement of children's play equipment, landscaping elements or other objects in formerly paved areas.

? **introducing changes in the vertical profile of the street**, such as raised intersection tables or the use of cobblestone ramps to carry car traffic up and down from crossing of continuous raised sidewalks and bicycle paths which must be crossed with caution.

Although it is commonly believed by some t**raffic engineers that slowing down traffic will increase emissions, evidence from Europe indicates that in many cases the exact opposite is true. Research in Germany has shown that the greater the speed of vehicles in built-up areas, the higher is the proportion of acceleration, deceleration and braking, all of which increase air pollution. By contrast, research in Germany indicates that traffic calming reduces idle times by 15%, gear changing by 12%, brake use by 14%, and gasoline use by 12%. (Peter Newman and Jeff Kenworthy, *Winning Back the Cities*, Pluto Press, Leichhardt NSW, Australia, 1992, p.39-40. citing C.Hass-Klau, editor, *New Ways of Managing Traffic* (title of issue), *Built Environment*, 12 (1/2). 1986.)**

This slower and calmer style of driving reduces emissions, as demonstrated by an evaluation in Buxtehude, Germany. The table below shows the relative change in emissions and fuel use when the speed limit is cut from 50 km/h (30 mph) to 30 km/h (20 mph), for two different driving styles. Even aggressive driving under the slower speed limit produces lower emissions (but higher fuel use) than under the higher speed limit, although calm driving produces greater reductions for most emissions and net fuel savings. (Peter Newman and Jeff Kenworthy, *Winning Back the Cities,* Pluto Press, Leichhardt NSW, Australia, 1992, p.39-40. citing T.Pharoah and J.Russell, *Traffic Calming: Policy Evaluation in Three European Countries*, Occasional Paper 2/89, Department of Planning, Housing, and Development, South Bank Polytechnic, London.).

Changes in Vehicle Emissions and Fuel Use
From 50 km/h to 30 km/h

Emission Type	Driving Style	
	2nd Gear Aggressive	3rd Gear Calm
CO	-17%	-13%
HC	-10%	-22%
NOx	-32%	-48%
Fuel Consumption	+7%	-7%

Source: Peter Newman and Jeff Kenworthy, Winning Back the Cities, Pluto Press, Australia, 1992, p.40.

Moreover, by encouraging more use of walking and bicycling and reducing the advantage offered by the automobile for short trips relative to these alternatives, traffic calming usually reduces the number of trips, trip starts, and VMT. Applied on a widespread basis in conjunction with transit improvements and transportation pricing changes, traffic calming may contribute as well to a reduction in household automobile ownership levels, further reducing emissions and travel demand. Thus, even in circumstances where individual vehicle emissions per mile traveled increase due to more aggressive acceleration, braking, and use of second gear, traffic calming will likely lead to overall emission reductions due to its influence on travel demand.

A 1993 report for FHWA (Project for Public Spaces, *The Effects of Environmental Design on the Amount and Type of Bicycling and Walking*, National Bicycling and Walking Study, Federal Highway Administration, October 1992, Washington, DC, p.15. citing CART, *Traffic Calming,* Ashgrove, Australia, CART, 1989) discusses the German experience with traffic calming demonstration projects in six cities and towns in the early 1980s:

The initial reports showed that with a reduction of speed from 37 km/h (23 mph) to 20 km/h (12 mph), traffic volume remained constant, but there was a 60% decrease in injuries, and a

43% to 53% reduction in fatalities. Air pollution decreased between 10% and 50%. The German Auto Club, skeptical of the official results, did their own research which showed broad acceptance after initial opposition by the motorists. Interviews of residents and motorists in the traffic calmed areas showed that the percentage of motorists who considered a 30 km/h (18 mph) speed limit acceptable grew from 27% before implementation to 67% after implementation, while the percentage of receptive residents grew from 30% to 75%.

This experience of initial skepticism of traffic calming, followed by its widespread popularity after implementation, has been experienced in hundreds of communities across Europe, Japan, and Australia, along with the a large number of U.S. communities which have adopted such strategies in the 1990s. The widespread acceptance of traffic calming in recent years by U.S. traffic engineers (particularly with promotion by the Institute for Transportation Engineers) and by many communities makes this strategy a reasonably available TCM everywhere today.

Street space needs to be allocated to the bicycle in areas where traffic volumes or traffic speeds are high if bicycles are going to be used to reach these areas. The majority of all streets and roads are already quite suitable for bicycling, with relatively low traffic speeds and low traffic volumes. However, such residential streets usually lead to bicycle-hostile major roads before reaching major activity centers and schools. Frequently, development of a few small missing links can make the difference between safe bicycle access and lack of bicycle access. Without separate bicycle paths or bicycle lanes, only the small share of cyclists who are more highly skilled will be attracted to use this mode of transportation to make day-to-day trips. Experience in many cities and towns in America and elsewhere shows that high levels of bicycle use only occurs where the street system is bicycle-friendly. Where well-connected networks of bicycle friendly streets, bicycle paths, and bicycle lanes have been provided -- such as Davis, Palo Alto, and Santa Barbara, California, Madison, Wisconsin, and Gainesville, Florida -- bicycle mode shares of 10-25% are common. Where such networks are not available, only the hardiest of cyclists take to the roads for purposeful travel, leading to bicycle mode shares of 2% or less. These relationships can also be observed in other affluent countries in Europe and Asia. (Michael Replogle, *Bicycle and Pedestrian Policies and Programs in Asia, Australia, and New Zealand,* U.S. Federal Highway Administration, Washington, DC 1993).

A large share of major activity centers and transit stops across America lack safe and convenient bicycle parking. Provision of such facilities and encouragement of employers to provide showers and changing facilities for bicycle commuters can remove significant barriers to bicycle use. Bicycle theft and vandalism is a major deterrent to bicycle use. One study in Baltimore, Maryland, found that 25% of those polled had had their bicycles stolen and that 20% of these theft victims had given up bicycling as a result of the experience. (Katie Moran, *Bicycle Transportation for Energy Conservation: Technical Report,* U.S. Department of Transportation, 1980, Washington, DC, p.38). Bicycle theft rates per capita are significantly higher in the U.S. than in most European cities and many times higher than in Japan. (Michael

Replogle, *Bicycles and Public Transportation: New Links to Suburban Transit Markets*, Bicycle Federation, 1984, Washington, DC).

Bicycle Access to Transit. Experience suggests that improving bicycle access to transit may be among the most promising but neglected strategies to enhance air quality while increasing the freedom of travel choice. Bicycles are the fastest growing and predominant mode of access to express public transportation services in many European communities and in Japan, as well as in some American communities. Provision of secure bicycle storage at rail stations, development of bicycle-friendly street networks, and the creation of a climate of community opinion supportive of bicycling are all important factors behind the success of bike-and-ride systems in these countries. Automobile park-and-ride trips involve cold start vehicle operation, with associated pollution emission and fuel use rates several times higher than the average for all automobile travel, resulting at times in almost negligible emissions reductions from park-and-ride, when all factors are considered. In contrast, bicycle and pedestrian access to transit has zero emissions. Switching short automobile access trips to bicycles can free up park-and-ride spaces for travelers living more than two miles from the lot, improving the cost-effectiveness of the overall transit access system.

APPENDIX D

INDEPENDENT REVIEW OF
"MOVES DESIGN AND EMISSIONS ANALYSIS PLAN"

BY

ARMISTEAD RUSSELL
PROFESSOR
GEORGIA INSTITUTE OF TECHNOLOGY

Review of EPA MOVES "Draft Design Plan for EPA's Multi-Scale Motor Vehicle & Equipment Emission System"

By Ted Russell

The document "Draft Design Plan for EPA's Multi-Scale Motor Vehicle & Equipment Emission System" provides a good overview of the initial design considerations for the new MOVES system, though definitely written for the mobile source modeling community, and could probably benefit from being written to a broader audience, if for no other reason to identify how other communities might also use MOVES. In the following review I have attempted to address the specific points identified. The points, as well as the responses, follow.

- **Do the use cases presented in the document appropriately capture the needs of mobile source emissions modelers?**
    - First, the question should be asked not from the needs of the mobile source emissions modelers, but of the air quality community in general.
    - The use cases are generally well thought out, thought should be taken one or two steps further. In particular, you will see much more use of mobile source emissions model outputs being used by the health community. There is a growing body of evidence that living close to highways increases certain health outcomes. This will lead to investigators wanting to use spatially and temporally detailed emissions estimates that can be directly used in exposure studies. I do not put this in the toxic exposure use case, though that may be the intent, since many of the pollutants of interest may not be on the toxics list, and is not a traditional "hot spot" or project level analysis function. It is important, at this juncture, to design MOVES with the health community in mind. This means that emissions estimates with resolution at the 100m scale along a roadway may be of importance.
    - Similar, some modelers are now going to advanced and more detailed approaches such as large eddy simulation (LES) that will require more detailed information, e.g., they may want information on which lane the emissions are generated. While I don't think this will be a large need, having that type of capability should be considered. Keep in mind that the major limitation to very detailed air quality modeling will not be the simulation time required, but the ability to provide data at the finest spatial and temporal scales that would be required.
    - In terms of Model Analysis, in addition to validation, one should add evaluation, as the two are different.

    - **Does the proposed model design satisfy these use cases as suggested by EPA?**
    - While in general, it does appear that the design can accommodate the use cases, I am a bit concerned that its design may not interact with SMOKE

adequately. A growing number of users are moving to SMOKE, so making that connection as seamless as possible is important. In particular, do all of the data structures being used by MOVES work with those being used by SMOKE? While noting that MOVES should work with SMOKE, the level of detail in the document is not sufficient to say this will be the case. In fact, one should look at the ability to encapsulate MOVES into SMOKE at some point, or at least have that possibility supported.

- I saw little in the design to deal with visualization. This is an important need. I would recommend that the output be usable by programs like PAVE, which is probably the dominant system for visualizing air quality information, and widely used by EPA for air quality studies.

- **Does the proposed model design allow for a range of input data options that is sufficiently broad to not impose an undue burden on low-end users while allowing sufficiently flexible for highly specific applications?**
- Before responding to this question, the designers should pay particular attention to the development of EPA's Models 3. My interpretation of what happened was that they tried to make the environment (human-system interface) too functional, resulting in greater complexity in the design and use. As such, most users (all of the ones that I know of) use the models in a stand alone fashion using run-scripts, and bypassing the interface. The redesign is to be simpler. Thus, keep it simple, and allow for regular users and more sophisticated programmers bypass the interface entirely. After reading the Run-Spec GUI Details in Appendix A, I became worried that it could rapidly become too complicated. At this point, if it is kept as simple as suggested in the document, fine, but the early discussions about the Models 3 interface left me with the same impression. Keep in mind a large majority of the users will be readily familiar with mobile source modeling and willing to spend some time to learn how to operate the system.
- If EPA does provide the defaults suggested, the low-end users should be adequately served. I am more concerned about the high-end users. Will it allow for sub-link scale analysis, e.g., taking information about roadways at a spatial scale below a link (again, say 50-100m) in a convenient way. This did not appear to be addressed.

- **The panel should review the mathematical formulations presented in Section 7. Do the formulations for the total activity generators and operating mode distribution parameters fulfill the stated purpose of the generators? Are there alternative formulations that should be considered? Are the proposed data sources discussed as possible inputs for parameters, both at the default and local levels, readily obtainable and the best available? Are there alternatives that should be considered? Are the levels of aggregation proposed in each step appropriate? Are there specific steps which are either over specified or**

are not disaggregated enough to account for the needs of users and real emission variability?

- While it is orthogonal to the design of MOVES, it would be useful to include the ability to conduct, primarily for comparison purposes, fuel-based emissions estimates. This may be best done by estimating fuel use at a more aggregated level, applying an emissions factor, and comparing to the approach(es) that MOVES is using. I consider this more of a reality check to make sure the two approaches are not significantly off.
- I would recommend that an approach besides binning be explored for VSP. Binning leads to discontinuities that likely do not exist in the fleet emissions distributions given the wide range of vehicles. Thus, a continuous function would seem appropriate, and has the added benefit of being differentiable, which can help for sensitivity and uncertainty analysis. One could fit a Chebychev polynomial to the data for stability.
- The document makes mention of conducting uncertainty analysis, with greatest emphasis on Monte Carlo methods. While it is understood that this area is largely still in the "we plan to include this feature" stage, a few thoughts:
  - As noted, Monte Carlo can be time consuming, and thus it is often more effective to develop direct methods. In addition to being faster, this also identifies (and quantifies) sensitivities directly. This should be done.
  - If one is to use MC, also add the ability to conduct regression analysis to identify the dependencies and global sensitivities.
  - Make sure that the MC analyses are properly constrained, e.g., that none of the variables go out of their domain when sampling the various parameters. There are constraints on various interdependent variables that may be violated if extreme values are sampled from other variables.

In addition to the above comments, some other thoughts coming from an air quality modeler: I think that the document was hinting at the ability to archive calculations, and then do modifications to the archived results without re-running the whole calculation. For example, if a specific area added I/M, one should be able to just re-run the calculation for the affected area to modify the archived results. This was a designed feature in SMOKE to minimize the need to rerun calculations. It was not apparent as to how easy this would be to conduct in practice.

It was not apparent to what extent the capabilities of COMPLEX would be added to MOVES. This is problematic since the data used to develop COMPLEX is not robust (in terms of model years tested, etc.), but MOVES should be able to deal with fuel properties and reformulation issues, beyond RFG vs. conventional as suggested on page 24. Even if the data is not currently available, adding the functionality should be done.

Does EPA plan to provide a site for maintaining MOVES, and also for maintaining an ever increasing data base? If not, who will? This is an important question in the design, since the design needs to account for how the code will be maintained, and how that impacts complexity and data availability.

Will the system be readily modified by others and EPA itself? Is the coding going to be well documented? Like Models 3, it would be very good if the model is developed in such a way as to be readily modified by groups doing research in this area, e.g., a community model, and care should be taken to not have dead and confusing code. Also, it would be good to try to minimize the differences between MOVES and the CARB equivalent at the time. Is it possible to get a common model?

What provisions are being designed in to identify errors and do quality assurance, e.g., statistical analysis of the results to target problems, as well as to do sub-domain analyses?

“Units” (in quotes because it is unitless) should be added for road grade in the equation for VSP on page 54, that is, it should be made explicit how grade is being measured. Also, what is the functionality of C_D on V? Is the dependency small enough to ignore?

On page 56, fuel-use can also be used as a measure of activity for off-road emissions.

It should be noted that FORTRAN, if well written, is quite portable across platforms, but requires an additional compiler.

Must the system be defined to run only on Windows©? More and more, advanced computer modelers are using other systems (LINUX) and maintaining it on Windows© could become tedious as Windows© changes. LINUX is probably more stable. Again, Windows© may be most accessible to the low-end users, but higher end users may not be as pleased. Again, this suggests that the design is more towards the low-end users.