U.S. EPA's MOVES2010 vehicle emission model: overview and considerations for international application

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Abstract

U.S. EPA recently released its new mobile source emission model, MOVES2010, which reflects several significant updates from its predecessor, MOBILE6. MOVES is a new modelling platform built to support multiple scale analysis, from detailed "project level" assessments to emission inventories at the regional or national level, for greenhouse gases, so-called "criteria" air pollutants, and air toxics. To support multiple scale analysis, MOVES has adopted a "modal" emission approach, which provides more flexibility in predicting emissions for different driving patterns, and allows assessment of emission impacts due to changes in vehicle acceleration as well as vehicle speed. Using a modal approach also enables a much broader assessment of vehicle emissions from multiple data sources, including inspection/maintenance programs, remote sensing data, portable emission measurement systems (PEMS), and traditional laboratory data. The updated emission estimates from MOVES2010 show significant increases in NOx and PM emissions relative to MOBILE6, which have been verified against independent data sources.

MOVES2010 was developed to allow customization to local areas, so that U.S. state and local governmental agencies can satisfy legislative mandates for air quality and transportation planning. These customization features give MOVES broad flexibility for international application as well. This paper discusses different "tiers" for international customization of MOVES. A first level would be to input custom vehicle fleet and activity data such as vehicle age distribution, vehicle distance travelled, and vehicle population; this level of customization could proceed quickly if such local data were already available. A second level of customization would focus on developing vehicle emission rates reflecting the emission standards applicable to the country being modelled. A final level of customization would be to implement more fundamental changes such as adding vehicle types, road types, or driving patterns. This paper will provide details on this tiered approach, with some consideration for the trade-off between increased customization and data collection burden.

Introduction

MOVES (MOtor Vehicle Emissions Simulator) is the U.S. Environmental Protection Agency's (EPA) new model to estimate air pollution emissions from mobile sources. MOVES2010, the first official release of the model, was recently made public and replaces EPA's previous emissions model for on-road mobile sources, MOBILE6.2. A new modelling platform was developed to support multiple scale analysis, from detailed "project level" assessments to emission inventories at the regional or national level, for greenhouse gases, criteria air pollutants, and air toxics. MOVES2010 estimates emissions for all types of on-road vehicles from tailpipe, fuel evaporation, brake wear, and tire wear sources. EPA ultimately plans to expand MOVES to include off-road emissions sources such as construction and agricultural equipment, locomotives and marine vessels.

MOVES development began almost a decade ago, in response to a report from the U.S. National Academy of Science (NAS) that recommended several improvements to EPA's mobile source modelling program. Among the major recommendations were to allow modelling at multiple analysis scales, to address the emerging need to estimate emissions at emission "hotspots" and to assess the local emission impacts of specific transportation projects. Another key recommendation was to develop a system which could be more easily updated with new information. The design of MOVES was greatly influenced by these NAS recommendations.

MOVES employs a completely new software framework that provides more flexibility for model input and output. The model is coded in JAVA, enabling a user-friendly graphical user interface, and stores input and output data in a MySQL relational database structure. This structure means the model is defined by data tables, allowing changes to standard inputs such as vehicle activity and fleet composition, on up to fundamental model elements such as vehicles classes or roadway types. These features will make it easier for users to develop local data for MOVES, and to further customize the model for international application.

The design of MOVES provides international users with a large degree of choice in reflecting their local conditions. Users may wish to rely on U.S. defaults as much as is practical, using local data for only critical inputs such as vehicle distance travelled; or, users may wish to fully customize the model with the driving patterns, emission rates, vehicle classes and road types unique to their area. The degree of customization is of course a function of the time and resources available to the modeler. This paper will lay out a "tiered" approach to customization, consider the types of data needed for each tier, and implications of increased customization.

Overview of MOVES2010

Extensive documentation on MOVES, including a users' guide and design manual, can be found on the MOVES website (http://www.epa.gov/otaq/models/moves). This section gives a brief overview of the model.

For a specified geographic location and time period, MOVES2010 will produce either total inventory (mass emissions), or emission rates (e.g. g/km) for the following pollutants:

- HC (THC, NMHC, NMOG, TOG, VOC)
- CO
- NOx (NO, NO_2)
- NH_3
- SO_2
- PM_{10}, $_{2.5}$ (organic carbon, elemental carbon, sulfate, brake wear, tire wear)
- Greenhouse Gases (CO_2, CH_4, N_2O)
- Toxics: Benzene, Ethanol, MTBE, Naphthalene, 1,3-Butadiene, Formaldehyde, Acetaldehyde, Acrolein

The model estimates energy consumption as well for total, petroleum, or fossil-based energy.

Users can request output in various levels of breakdown, according to the following categories:

- **Vehicle Class** (known in MOVES as "Source Types"), are organized around different patterns of vehicle activity. Source types can be added for further customization. In the default implementation of MOVES these are:
    - Motorcycle, Passenger Car, Passenger Truck, Light Commercial Truck, Bus (Intercity, Transit, School), Heavy Trucks (Single Unit / Combination: Short Haul / Long Haul), Refuse Truck, Motorhome
- **Road Type** is defined by different driving patterns expected to occur on each. These can also be added for further customization. In the default implementation of MOVES these are:
    - Urban Restricted (freeway), Urban unrestricted (non-freeway), Rural Restricted, Rural unrestricted
- **Emission Processes** are defined by unique combinations of how and when emissions are produced. These are:
    - Running, Start, Extended Idle ("hoteling"), Evaporative (Permeation, Vapor Venting, Liquid Leaks), Refueling (Vapor loss, Spillage), Crankcase, Tire Wear, Brake Wear
- **Fuel Types** are defined by unique vehicle technology, and are currently limited to gasoline, diesel, CNG, and electric. Additional fuel technologies, notably FFVs, will be added over time.
- **Model Years** go back 30 years from the calendar year being modeled, and can be output by year.

As noted, one important new feature of MOVES is the option to calculate emissions as emission rates (emissions per unit of distance for running emissions or per vehicle for starts, extended idle and resting evaporative emissions) in a look-up table format.

Analysis Scales

A key feature of MOVES is the ability to assess emissions at different analysis scales. Three analysis scales are supported in MOVES:

- "National" scale is focused on producing national emission inventories for the U.S. down to individual counties, making use of a large database of default information for vehicle fleet, meteorology, fuel and activity data. The defaults are focused specifically on U.S. emission estimation, making this scale less applicable internationally.
- "County" scale is focused on producing regional emission inventories based on pre-defined geographic areas (defined as counties in U.S. implementation), or for "custom domains" defined by the user. The "custom domain" feature is well suited for the development of regional emission inventories outside the U.S. This scale requires local data from the user, such as vehicle distance travelled, fleet age distribution and vehicle speed distributions.
- "Project" scale is focused on smaller-scale environments such as intersections, roadway expansions, or parking lots. Modelling is performed at the individual link level and allows for modelling of custom driving patterns. This scale has the largest demand for user data to define the environment being modelled, making it highly adaptable for international use.

MOVES was developed so that the same calculation procedures are in place for each scale. The different scales are largely defined by the vehicle fleet and activity data required for each, while using a common set of emission rates. Fuel and meteorology data can also be shared between scales.

Figure 1 shows a schematic of the data flow for MOVES at each scale. Increasing levels of data are required from the user as the scale shifts from coarse (national) to fine (project).

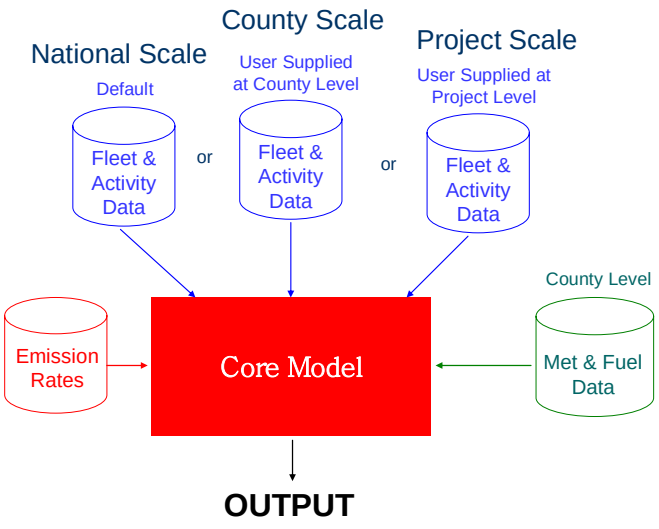


Figure 1: Schematic of MOVES data flow for different analysis scales

Modal Emissions

One of the groundbreaking elements of MOVES is the use of a "modal" emission approach. This allows the fundamental shift from aggregate driving-cycle based emission factors, such as those employed in MOBILE, to a model which can predict emissions over any driving pattern. MOVES uses the metric Vehicle Specific Power (VSP) to do this, enabling emission rates to be developed from a broad range of data, including laboratory, inspection/maintenance, on-board measurement, and remote sensing. For "running" (over the road) emissions, emission rates are characterized by bins of VSP and vehicle speed, as shown in Figure 2.

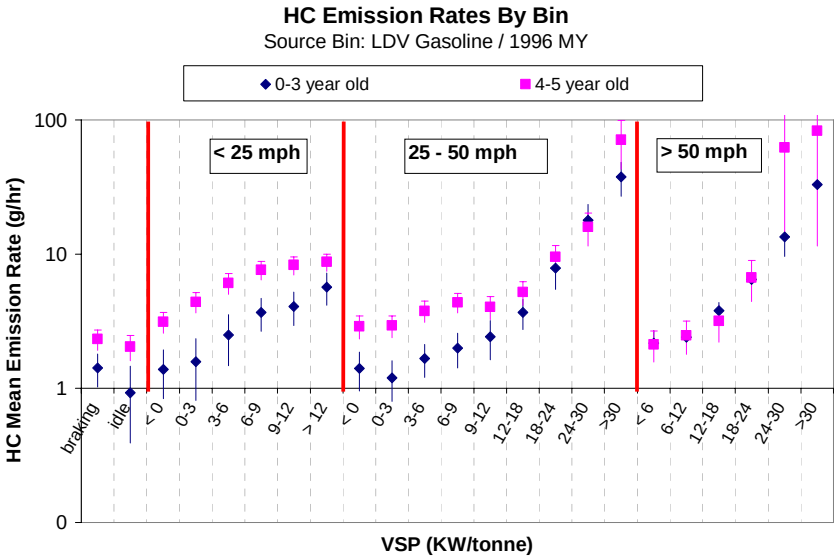


Figure 2: HC emission rates by VSP & Speed bin, shown for two model year groups

Driving activity is then expressed as the distribution of time spent in these bins, as shown in Figure 3. The summed product of emission rate and distribution by bin gives the estimate of average emission rate for a given driving pattern.

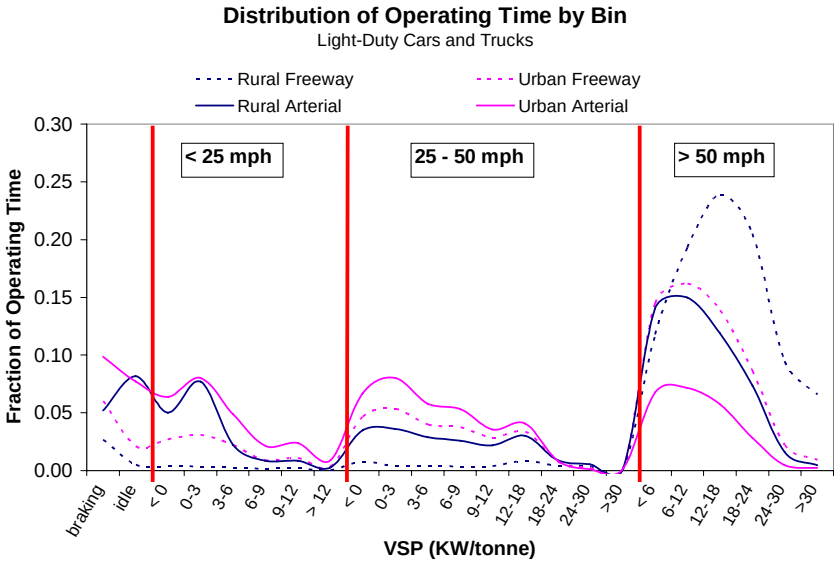


Figure 3: Distribution of time by VSP & Speed bin shown for four road types

This enables a new dimension for vehicle emission modelling – whereas MOBILE could only assess emissions as a function of average speed, MOVES now allows the user to assess emissions by average speed *and* the type of driving that resulted in the average speed – e.g., smooth driving vs. transient driving. This is demonstrated in Figure 4 for CO_2, but applies to nearly all of the pollutants MOVES models.

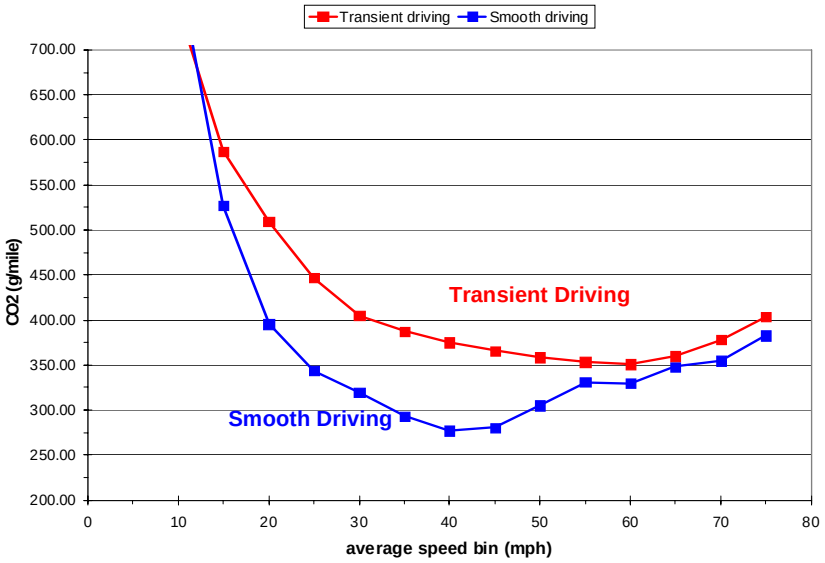
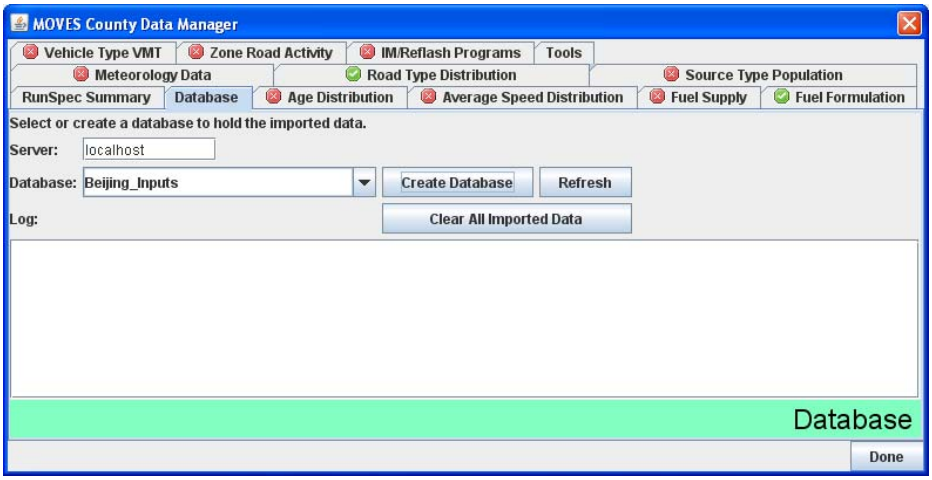


Figure 4: CO2 vs. average speed curve for smooth and transient driving

Customizing MOVES

MOVES was developed to facilitate a large degree of local area customization. The MOVES installation package includes a default database of meteorology, vehicle fleet, vehicle activity, fuel, and emission control program data for the U.S., but localities in the U.S. are encouraged to replace these defaults where better local data is available.

EPA has published technical guidance to assist U.S. areas in developing these improved inputs, centered on a MOVES feature known as the "County Data Manager" (CDM). The CDM is a graphical interface which allows users to import more commonly available data such as vehicle distance travelled, average speed distribution, or vehicle age distributions. The CDM allows easy import of custom data in MS Excel format, and converts to the MySQL data schema used by the model, rather than requiring the user to work directly in MySQL. A screenshot of the CDM is shown below:



The "Custom Domain" selection under the "Geographic Bounds" panel of the MOVES interface allows the user to define a new geographic area – from a metropolitan area to an entire country - and provide necessary information for the model to produce emissions for that domain. The County Data Manager feature in MOVES is used to enter data for custom domains as well. This feature allows users outside the U.S. to define their own modelling domain, without being constrained by the U.S. - based "county" designations.

Beyond the CDM, further customization of MOVES is possible working directly with the MySQL database. Users can replace all default data if desired, developing an alternate MySQL database to overlay default data in the execution of the model. Alternate databases are specified in the "Manage Input Datasets" panel of the MOVES graphical interface. Potential customization at this level could include new driving patterns, new emission rates, or even fundamental changes such as vehicle classes or road types.

Proposed Approach For International Application

Recognizing that to fully customize MOVES outside of the U.S. would require a substantial data collection effort, a "tiered" approach to customization is recommended, to make use of data that is more likely available in the short term. The focus here is for regional emission inventory development, as project level already requires a great degree of customization. This approach is predicated on the use of the "Custom Domain" option by users to define and customize their region(s) of interest. Once this custom domain is established, the recommended tiers are as follows:

1. **"1st Tier": Use County Data Manager to input more commonly available local data.** This is the process any U.S. city would use to customize MOVES, as detailed in EPA guidance. Users would supply local activity, fleet distribution, and fuel parameters through the CDM; if these data are available this could be done relatively quickly. However, the resulting model would be based on default U.S. emission rates reflecting U.S. standards, and the driving patterns, vehicles classes and road types already in MOVES2010.

2. **"2nd Tier": Implement specific emission standards.** Alternate emission rate data tables could be developed to reflect different emission standards (Euro, Asia etc.) and implementation dates. This table could likely be developed from the default U.S. emission rates, by mapping Euro or Asia vehicle technologies or standards to their U.S. counterparts; or, an area that had a body of local emission data could develop all new rates. In combination with the 1st Tier, the resulting model would be highly customized but would still reflect the driving patterns, vehicles classes and road types already in MOVES2010.

3. **"3rd Tier": Develop alternate MySQL database for more fundamental changes.** For users wishing complete customization, an alternate MySQL database could be developed to add vehicle classes (e.g., taxis, BRTs), road types, or driving patterns. The resulting model could reflect the local situation to a very large degree, but would likely require an extensive research program to generate the data needed for these fundamental changes.

For many international applications, the 2nd tier would likely provide the best trade-off between customization and resource burden. That this would provide good model performance outside the U.S. is based on the hypothesis that individual vehicle emissions differ little between U.S. and other countries, once emission standards are accounted for. Vehicle technologies are similar at comparable standard levels, so differences in deterioration, VSP, temperature, fuel effects would not be expected just because a vehicle is outside U.S. (though this hypothesis could be tested over time by comparing local emission data to MOVES emission rates). Fleet characteristics and activity patterns are a much larger source of difference, and these would be addressed mainly through data entered in the CDM as described in the 1st tier.

Conclusion

The U.S. EPA's MOVES2010 model reflects many advancements for mobile source modelling, and was developed to allow a large degree of customization, making it highly adaptable outside the U.S. International users will need to consider how much customization is needed, based on an assessment of their local needs, available data and resources. This paper presents a "tiered" approach to aid in this consideration. A first tier would be to input custom vehicle fleet and activity data such as vehicle age distribution, vehicle distance travelled (e.g., VKT), and

vehicle population; this level of customization could proceed quickly if such local data were already available. A second tier would focus on developing vehicle emission rates reflecting the emission standards applicable to the country being modelled. The third tier would address more fundamental changes such as the number and categorization of vehicle classes, road types, and driving patterns. For many international applications, the second tier would likely provide the best trade-off between customization and resource burden. International users are encouraged to develop a plan for customizing MOVES according to these tiers, accounting for the resources and data available to them.

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