Overview of U.S EPA New Generation Emission Model: MOVES

Suriya Vallamsundar[1] and Jane Lin[2]
[1]University of Illinois at Chicago/ Dept of Civil and Materials Engineering, Chicago, U.S.A.
Email: svalla2@uic.edu
[2]University of Illinois at Chicago/ Dept of Civil and Materials Engineering, Chicago, U.S.A.
Email: janelin@uic.edu

***Abstract*—The U.S Environment Protection Agency (EPA) has released a new generation regulatory mobile emission model, entitled MOVES (Motor Vehicle Emissions Simulator) to replace its current emission models, MOBILE and NONROAD. The transition to MOVES will have important policy implications for regional mobile source emissions, particularly inventories associated with transportation conformity. The methodology of MOVES is based on a discrete binning approach compared to average speed based approach employed in traditional emission models. The scope of MOVES has been expanded to estimate emissions at national, regional and project scales, inclusion of number of pollutants and emission processes, alternative vehicle and fuel types. MOVES has an extensive database reflective of real world driving conditions developed by assessing millions of vehicles for a long period of time. Detailed description of methodology, scope and data of MOVES is presented in this paper. Using a case study of Cook County, Illinois emission estimates of green house gas namely carbon dioxide (CO_2) and a criteria pollutant namely nitrogen oxide (NO_x) are estimated by MOVES and compared to its predecessor, MOBILE6.2. The fundamental differences in emission estimation methodology between the two models are the reasons for different estimation results, with MOVES believed to be more accurate owing to its theoretical superiority over MOBILE.**

***Index Terms*—EPA, MOVES, Emissions**

I.INTRODUCTION

Although the United States accounts for approximately 5% of the world's population, it is responsible for 21% of the world's GHG emissions. The 1990 Clean Air Act Amendments (CAAA) requires states to attain and maintain the National Ambient Air Quality Standards (NAAQS). The requirements of the CAAA establish significant restrictions on transportation investments in areas already exceeding the Standards not to worsen the regional and local air quality. This regulatory process is known as transportation conformity. Generally speaking, mobile emissions are estimated by multiplying emission factors (in grams per mile or g/mi) with vehicle travel activity e.g., vehicle miles of travel (VMT) and number of vehicle trips. A number of energy and emission models were developed over the past decade to estimate emissions and energy consumption. Countries such as U.S and Europe have developed sophisticated emission models based on their local specific conditions, emission standards, vehicle and road types, fuel types, inspection/ maintenance programs. In the U.S, emission models can be categorized as macroscopic and microscopic models [1]. Macroscopic models use average aggregate network parameters to estimate network-wide energy consumption and emission factors. The primary macroscopic emission models used in the U.S developed for regulatory purposes have been the U.S EPA's MOBILE and California Air Resources Board's EMFAC model. Both these models are conceptually similar as they use network wide average speed as input to produce activity-specific emission factors which when multiplied with vehicle activities such as vehicle miles traveled (VMT) gives the total emission inventories. The main drawback of these models is in the use of a single traffic-related variable to estimate emissions thereby ignoring other important explanatory variables such as variations in speed and vehicle operating modes that can significantly affect emission estimates [2]. Microscopic models take into account the acceleration and deceleration of vehicles, which help capture the effects of different instantaneous speed and acceleration profiles on vehicle emissions thereby representing real driving conditions. Examples of early microscopic models in the U.S are the Comprehensive Modal Emissions Model and Virginia Tech Microscopic Energy and Emission Models. On the other hand, EPA has recently released the final version of the next generation microscopic mobile source emission model called the Motor Vehicle Emission Simulator (MOVES). MOVES is intended to include and improve upon the capability of the other microscopic emission tools and eventually to replace all of EPA's current emission models (MOBILE for on-road emission estimates and NON-ROAD used for off-road estimates) as the approved model for state implementation plans (SIPs) and transportation conformity analyses [3]. This paper presents a detailed description of MOVES methodology, scope and database in comparison to its predecessor MOBILE6.2. Since MOVES is a new model, there have been few studies reported in literature about MOVES or comparing it with MOBILE. Such studies are much in need for better understanding of the new model and for the purpose of smooth transit between the two models. To fill this void in the literature, this paper evaluates how well MOVES works as compared to MOBILE through a case study of Cook County, Illinois and explores the reasons for the difference. The following section gives a detailed description of MOVES. The methodology, scope and

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database are discussed in first three subsections followed by literature review in last subsection. The third section discusses the case study of Cook County. Finally the fourth section discusses the findings of the comparison followed by conclusion in the last section.

II.BACKGROUND

A. *Model Methodology*

MOVES follows a superior “modal approach” for emission factor estimation compared to the “driving cycle based approach” followed by MOBILE and calculates emission inventories or emission factors using a set of model functions. MOVES emission estimation model structure is shown in Figure 1. Four main functions constitute the framework of MOVES [4]: total activity generator (TAG), source bin distribution generator (SBDG), operating mode distribution generator (OMDG) and emission calculator. The input activity data in MOVES are vehicle miles traveled (VMT) and vehicle population indicated by “Fleet and Activity Data”. The TAG grows the base year vehicle population and VMT to analysis year using growth factors and categorizes them by road type, vehicle type and age, time period. MOVES applies a “binning” approach wherein each activity is binned or distributed according to different factors depending on the emission process and pollutant. The bins that differentiate activity according to vehicle characteristics that significantly influence fuel (or energy) consumption and emissions are labeled “Source Bins”. “Operating Mode Bins” differentiate the emissions according to second-by-second speed and vehicle specific speed (VSP). VSP represents the power demand placed on a vehicle under various driving modes and various speeds. After distribution of total activity into different bins, the emission calculator assigns an emission rate for each unique combination of source and operating mode bins and the emission rates are aggregated for each vehicle type. A few correction factors are applied to the emission rates to adjust for the influence of temperature, air conditioning and fuel effects to obtain the total emissions.

B. *Model Features*

MOVES includes all features currently present in MOBILE, while offering improved capabilities to perform new and existing function with more accuracy. MOVES produces emission rates as well as emission inventories compared to only emission rates produced by MOBILE. MOVES is a data-driven model with all inputs, outputs, default activities, base modal emission rates and all intermediate calculation data are stored and managed in MySQL relational database. This design also provides users with flexibility in constructing and storing their own database under the unified framework in MySQL. MOVES is designed to estimate emissions at scales ranging from individual roads and intersections (i.e., link level) to County, regional, and National scales. The “Macroscopic or National” scale is the default selection in MOVES. Data collected on a nation-wide level is apportioned or allocated to states or counties. With the “Mesoscopic or County scale”, the model will replace National default allocations with user-supplied data. “Microscopic or Project” scale is the finest level of modeling in MOVES. It allows the user to model the emission effects from a group of specific roadway links and/or a single off-network common area [5]. MOVES includes emissions estimates for a range of pollutants and emission processes. In particular, MOVES provides much more sophisticated, modal based estimation procedures than the simplistic fuel economy approach in MOBILE [6] for computing transportation energy consumption and greenhouse gas (GHG) emissions. MOVES enables modeling of advanced technology vehicles and alternative fuel types

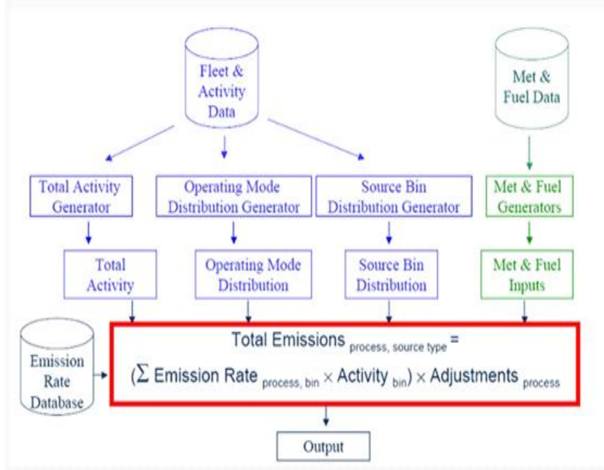

figure 1. emission estimation process in moves [7]

C. *Model Data*

The change in methodology in MOVES compared to MOBILE requires new inputs. In particular, because MOVES can calculate inventories and emission rates, MOVES relies on input of Vehicle Miles Travelled (VMT) and on vehicle population for estimating emissions corresponding to start exhaust and evaporative activity. The default emission rates in MOVES were developed by assessing millions of vehicles for a long period of time. This extensive default database includes vehicle activity, vehicle fleet, meteorology, fuel supply, inspection and maintenance (I/M) program for the entire United States. The data included in this database is composed from a variety of sources and are not necessarily the most accurate information available for performing regional or project level emission analysis [8]. Hence considerable effort is needed to obtain accurate local data to take advantage of MOVES’s capabilities.

D. *Relevant Work*

Since MOVES is a new model, there have been few studies reported in the literature assessing MOVES performance as compared to previous emission models. In a study by Sonntag et al., [9] a comparison between emission rates for methane (CH4) and CO_2 was made between macroscopic module of MOVES2004, an earlier draft version released in 2004, and MOBILE6.2. Their results showed that the difference in emission rates of CH4 showed the importance of alternative

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engine fuel types on future emission rates considered in MOVES. The aggregation levels significantly affected the CO_2 results in MOVES. In a study by Song et al., [10] the authors estimated CO_2 and CH4 for Los Angeles County for years 2002 and 2030 with macroscopic module of MOVES-HVI Demo, an intermediate draft version released in 2007 and EMFAC. The authors found that CO_2 emission difference appeared to be a function of VMT estimates and CH4 emission difference were dependent on base emission rates. Beardsley et al., [11] (2010) compared MOVES2010 and MOBILE6 emission estimates for three sample urban counties. Their results showed that MOBILE6 underestimated NO_x especially from light duty and particulate matter (PM). With respect to hydrocarbons (HC), the results show that MOBILE6 overestimated HC emissions especially from newer technology cars. It is worth noting that most of these studies have focused on macroscopic scale wherein the data collected on a national level is allocated to states or counties. These allocation factors are a function of the fraction of total U.S VMT that occurs in counties, based on the federally mandated inventory Highway Performance Monitoring System (HPMS). However the allocation of the default data to the county level is based on a generalized algorithm that does not take into account factors that differs between areas of the country. The main advantages of using local specific data would be to better represent the vehicle activity and conditions for use in conformity demonstrations and SIP purposes [4]. In this study, a comparative analysis between MOVES and MOBILE is made at the mesoscopic scale utilizing the local specific data for Cook County, Illinois; which is more accurate compared to the default national scale.

III.CASE STUDY: COOK COUNTY, ILLINOIS

The purpose of this case study is to compare the emissions of a criteria pollutant namely NO_x and green house gas namely CO_2 between MOVES and MOBILE. MOVES scenario runs are specified using mesoscopic module in the latest 2010 version and MOBILE runs are specified using latest 6.2 version. For maintaining consistency, both models are run for the same scenario at matched temporal and spatial scales: for a week day in the month of July, 2009 for Cook County located in Illinois. Cook County is the second most populous county in the U.S after Los Angeles County. Cook County has the highest population, the highest population density, the largest extent of urban land cover, and the highest level of vehicular traffic of all the counties in the Chicago metropolitan area. Table 3 shows the mileage and annual VMT by functional classification in Cook County based on the latest 2009 HPMS data. Cook County is classified as a non-attainment area for 8-hour ozone and 24-hour PM2.5 standard, which has caused inspection/maintenance programs fixed as a prerequisite for vehicles registration. Fuel supply in Cook County is reformulated gasoline. The year 2009 is selected as the latest VMT data available from the HPMS is available for this year. Table 2 lists the input parameters used in this study. Local specific data for MOVES2010 is obtained from three sources: existing MOBILE6.2 input files, HPMS and MOVES default database. To convert data from MOBILE6.2 input file format into MOVES compatible format, converters released by EPA are utilized [12].

TABLE I. MILEAGE AND ANNUAL VMT IN COOK COUNTY

Facility	AVMT (in thousands)	Miles
Interstate	11,272,833	213.91
Other Principle Arterials	7,642,364	641.7
Minor Arterials	6,059,233	1024.9
Collectors	4,441,824	1204.3
Local Roads	3,532,968	8181.9
System Totals	32,949,222	11,266.7

IV.RESULTS

Emission inventories of NO_x and CO_2 obtained are presented in Table 3. Total energy consumption is an additional output given by MOVES2010 as CO_2 in MOVES is calculated based on total energy consumption From the results, it can be seen that MOBILE6.2 underestimates both NO_x and CO_2, only 70% of NO_x and 85% of CO_2 emissions estimated by MOVES2010. The calculation of emissions is dependent on vehicle activities and associated emission factors. With the same vehicle activity data from HPMS incorporated into both models, the difference in emission estimation is solely dependent on emission factors, which in turn depend on the methodology incorporated by the models in calculation of emission factors. Calculation of emission factors generated by MOVES represents a more accurate characterization of on-road emissions than use of emission factors by MOBILE based on average speed. This is due to the modal based approach followed by MOVES in calculation of emission factors that can account for different patterns of acceleration, cruising and deceleration as well as average speed. MOVES provides a detailed breakdown of emission factors by source and operating mode bins which takes into account the vehicle characteristics and second-by-second drive schedule based on speed and VSP. On the other hand, emission factors in MOBILE are directly related to a single average speed that correspond to a fixed VSP distribution used in the development of baseline driving cycles. Studies [13], [14] have shown that VSP has better correlation with emissions than use of single traffic related variable (average speed). With respect to GHG emissions, MOVES2010 calculates CO_2 from total energy consumption based on source

TABLE II

0	MOBILE	MOVES
Version	MOBILE6.2	MOVES2010
Pollutant/ GHG	NO_x, CO_2	NO_x, CO_2
Process	Running Exhaust	Running Exhaust
Road Type	Freeway Arterials, Collector Local Freeway ramps	Rural Restricted Access Rural Unrestricted Access Urban Restricted Access Urban Restricted Access
Vehicle	Passenger Cars (Gasoline)	Passenger Cars (Gasoline)
Min/ Max Temperature	13F/ 29 F	13F/ 29 F
Absolute Humidity	21.2	21.2
Calendar Year	2009	2009
Month	July	July
Altitude	Low	Low
Speed –VMT Distribution	Local data - MOBILE format	Converted from MOBILE input file
Registration Distribution	Local data – MOBILE format.	MOVES Default Database.
Inspection/Maintenance Program	Local data – MOBILE format	MOVES Default database for Cook County
Fuel Supply	Local data – MOBILE format	MOVES Default database for Cook County

and operating mode bins accounting for the carbon content of the fuel and oxidation factor. MOBILE6.2 calculates CO_2 emission rates based on carbon molecular mass balance, which does not account for changes in speed and other localized factors [6].

V. CONCLUSION

The replacement of EPA's current emission model MOBILE with MOVES will have serious implication for emission inventories and transportation conformity analysis. The key distinctive features of MOVES that make it superior to traditional emission models are (1) Estimation of both emission rates and total emissions (2) Model based approach for emission rate estimation (3) Availability of relational MySQL database management (4) Multi-scale emission analyses from regional down to link level (5) A number of emission process and pollutants estimated. In light of these new features, MOVES is expected to produce more accurate emission estimates at the regional and project level, the scales which are important for transportation conformity analyses. Future developments in MOVES modeling would be aimed at estimating pollutants from other mobile sources such as aircrafts, locomotives and commercial marine vessels. In addition, the capability toestimate non-highway mobile source emissions and to operate at smaller scales is planned.

TABLE III. COMPARISON OF EMISSION INVENTORIES

Emissions Totals	MOBILE 6.2	MOVES 2010	Difference
NO_x (tons/day)	20.64	30.1	+30%
CO_2 (tons/day)	19851.72	23378.27	+15%
Total Energy Consumption (tons/day)	-	325300511	-

Note: 1 ton = 907 kg

Using a case study of Cook County, Illinois, MOVES is compared with its predecessor emission model. MOBILE6.2 estimated only 70% of NO_x and 85% of CO_2 emissions estimated by MOVES2010. The underlying emission factors contributed to the observed differences between the two models as the same vehicle activity is applied to both models. The difference in CO_2 estimates is due to modal based estimation of CO_2 from total energy consumption in MOVES compared to the simplified fuel economy rates in MOBILE.

Underestimation/overestimation of emission can lead to serious policy implications. Policies such as GHG emission credits, cap-and-trade, carbon tax etc must rely on accurate estimation of emissions. For example, Cap-and-trade aimed at reducing GHG emissions sets a limit or cap on the amount of GHG pollution each firm is allowed to emit and provides economic incentives to firms that produce lesser emissions. Thus it can be seen that the core foundation of all these policies on climate change is the requirement to accurate emissions data which in turn depends on the emission models adopted in their estimation and their temporal, spatial resolution.

Finally, countries such as U.S and Europe have developed sophisticated emission models based on their local specific conditions, emission standards, vehicle and road types, fuel types, inspection/maintenance programs etc. Developing countries that do not have their own emission models have adopted emission models developed in U.S and Europe by making modifications suited to their local specifications. For example, Mexico [15] and Hong Kong [16] have modified MOBILE and EMFAC emission models to predict emissions suited for their corresponding local data. However, incorporating these models for different locations requires extension modifications in terms of base data used in development of emission rates to the existing model. These modifications have to be carried out extensively and exhaustively to make sure the model represents the current local conditions completely to avoid unreliable estimates.

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