

CRC Report No. A-88

**MOVES INPUT IMPROVEMENTS
FOR THE 2011 NEI**

Final Report

October 2014



COORDINATING RESEARCH COUNCIL, INC.

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MOVES Input Improvements for the 2011 NEI: CRC Project A- 88

FINAL REPORT

Prepared for:

Coordinating Research Council

Prepared by:

Eastern Research Group, Inc.

October 21, 2014



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1.0 ABSTRACT

The Coordinating Research Council (CRC) sponsored a project focused on developing improved inputs for EPA's Motor Vehicle Emissions Simulator (MOVES), for use in the 2011 U.S. National Emissions Inventory (NEI). Under contract with CRC, ERG identified the most promising MOVES inputs for improvement, and performed a detailed review of candidate data sources for each. From this detailed evaluation, ERG centered on passenger car and light truck age distributions and populations and long-haul truck VMT allocations, and developed improved defaults to be applied at the local level. Age distributions and vehicle populations were developed for every county in the U.S. based on vehicle registration database purchased from IHS, Inc. The age distributions showed an average age range of 4 to 16 years for cars and trucks vs. MOVES national default of 9 years. Long-haul truck VMT allocations were derived from the 2007 Freight Analysis Framework (FAF), producing unique allocations by region of the country, urban/rural and interstate/non-interstate, and are intended to replace the uniform long-haul allocations currently used in MOVES. The updated long-haul fractions for combination trucks varied by region of the country, road type and urban/rural area, ranging from around 30 percent on urban unrestricted roads, to up to 90 percent for some rural restricted roads, in comparison to a static MOVES default of 59 percent. These updates will be used in the 2011 NEI, and provide a resource for emissions modelers at the federal, regional, state and municipal levels to improve local inventory and air quality modeling. While not ultimately implemented in A-88, other important findings were made for MOVES inputs related to heavy-duty truck idling and vehicle start activity that could be considered for future model and emission inventory improvements.

2.0 INTRODUCTION

The Coordinating Research Council (CRC) has sponsored two projects aimed at improving the on-road component of the 2011 U.S. National Emissions Inventory (NEI), with a focus on evaluating and improving inputs used for EPA's Motor Vehicle Emissions Simulator (MOVES). CRC contracted with Eastern Research Group, Inc. (ERG) to undertake both projects. The first, referred to by the CRC project name A-84, analyzed MOVES input data submitted by 30 states for over 1,400 counties for Version 1 of the NEI, published in 2013.¹ This study found a large degree of variability in the data provided by states vs. MOVES defaults for the primary inputs: vehicle age distribution, vehicle miles travelled (VMT), vehicle population, road type distribution and speed. An emissions sensitivity analysis based on the range of the state-submitted data found the largest sensitivity to vehicle age distribution (for HC and CO) and combination long-haul truck VMT (for NOx and PM). This work underscored the importance of good local data for use in developing emission inventories in MOVES. In 2014 CRC sponsored project A-88 to build on these findings and develop improved default MOVES

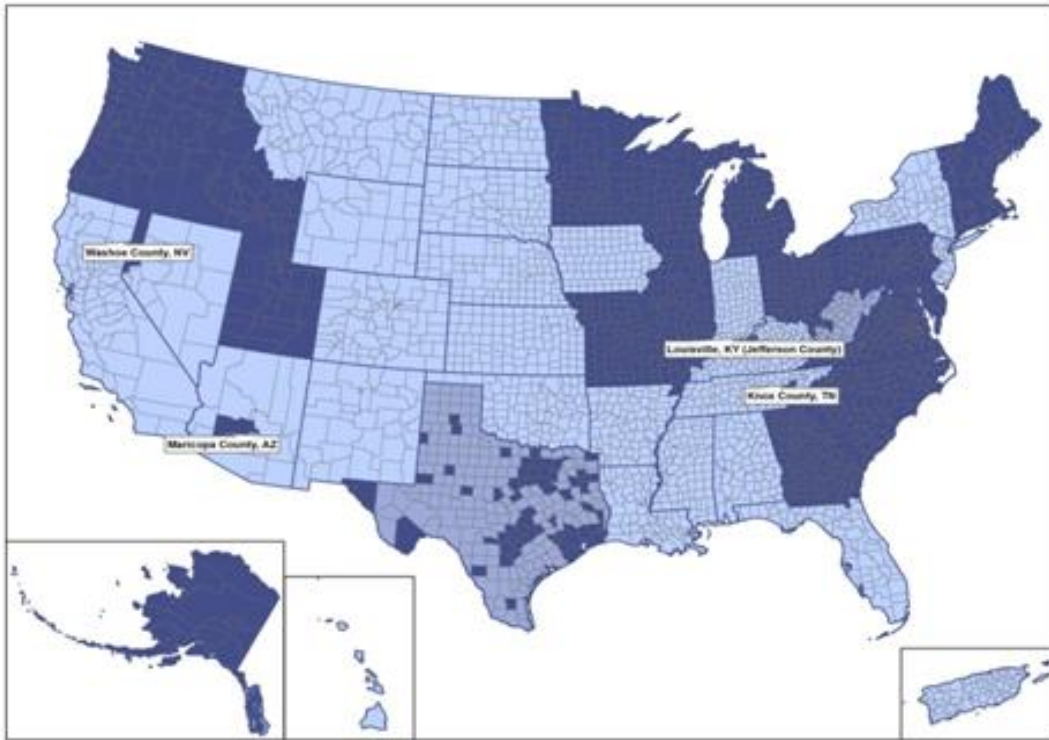
inputs for use in Version 2 of the 2011 NEI, to be developed in 2014. The focus of A-88 was on national datasets that could be used to improved default on-road inputs at the local level for the NEI, to improve the emission inventory for states that did not submit local data for the NEI. A corollary objective was to identify and evaluate data sources that could be used by modelers at the federal, regional, state and municipal levels to improve inventory and air quality modeling.

Work under A-88 was separated into two tasks. The first task was to determine the highest priority MOVES inputs for improvement, and assess national-level datasets that could be used to improve the inputs for Version 2 NEI. From this assessment, the second task then produced data for a subset of MOVES inputs, based on a) the importance of the input, and b) availability of data from which to make improvements. Because the end products of A-88 were to be used in EPA's development of the on-road NEI, EPA, CRC and state inventory modelers were close collaborators with ERG throughout the project.

3.0 INITIAL SCREENING OF MOVES INPUTS

Task 1 focused on identifying the MOVES inputs that had the most potential for improvement over the current defaults. The pool of candidate MOVES inputs was defined by MOVES county database input that states can submit to the NEI, plus inputs requested by CRC and/or EPA during the course of the project. Some of the stated priorities of CRC and EPA broadened the focus of the evaluation beyond default MOVES inputs for non-submitting states (Figure 1), to MOVES and/or SMOKE inputs that are not requested of states as part of the NEI. The scope of these updates would therefore included all states, and carry into EPA's broader inventory and air quality work. The scope of the evaluation considered improvements to national MOVES defaults that would otherwise be used in every county in the U.S., regardless of whether states submitted data for other inputs. Through communication with EPA, it is clear that in addition to Version 2 of the NEI, the improvements to be made under A-88 would also serve to improve the on-road inputs EPA's air quality modeling platform and MOVES defaults.

**Figure 1. Version 1 NEI MOVES Submissions
(states not submitting data shown in light blue)**



As the focus on A-88 is improving inputs for the NEI, the pool for potential inputs numbers in the dozens and covers MOVES itself, and the SMOKE-MOVES model used to actually generate the on-road NEI. This pool of dozens of inputs is much broader than could be addressed within the scope of A-88, so it was necessary to narrow down the list of inputs to address in Task 2. ERG's first step in this was an initial screening process that drew on what was learned in the A-84 project, stated priorities of CRC and EPA, initial investigation of data sources, and ERG's experience on other projects. Initial screening based on A-84 and stated CRC/EPA priorities are discussed in the following sections.

3.1 Most Influential Inputs from A-84

A-84 focused on the MOVES county database (CDB) inputs that states are requested to provide for the NEI, entered through an interface known as the county data manager (CDM). A central outcome of A-84 was an assessment of the most influential inputs on total MOVES emissions. This process began with a qualitative assessment of the influence that every MOVES CDM input would have on NEI emissions (Table 1).

Table 1. Qualitative Assessment of MOVES CDM Inputs from A-84

MOVES Table	General Description	Expected Influence on NEI
avft	Fuel technology fractions (gas/diesel/CNG)	Medium – large variations in state-submitted data not expected
avgspeeddistribution	Distribution of average speeds	High – state-submitted data likely, significant variation from default likely, MOVES results highly sensitive to changes
dayvmtfraction	VMT distribution by weekday/weekend	Medium – not significant factor in annual inventories
fuelformulation	List of possible fuels in area	Low – do not expect states to submit new formulations
fuelsupply	Market share of fuel formulations	Medium – do not expect states to have comprehensive information on fuel market share
hourvmtfraction	Distribution of VMT by hour of the day	Medium – not a significant factor in annual inventories
hpmstypeyear	Total Vehicle Miles Travelled (VMT) by vehicle class	High – state-submitted data likely, significant variation from default likely, MOVES results highly sensitive to changes
imcoverage	I/M program parameters	Medium - states not expected to have significant changes
monthvmtfraction	Distribution of VMT by month	Medium - while more important for annual inventories than day/hour fractions, large variations from default not expected
roadtypedistribution	Distribution of VMT across road types	High - state-submitted data likely, significant variation from default likely, MOVES results highly sensitive to changes
sourcetypeagedistribution	Fleet age distribution	High - state-submitted data likely, significant variation from default likely, MOVES results highly sensitive to changes
sourcetypeyear	Vehicle populations	High - state-submitted data likely, significant variation from default likely, MOVES results highly sensitive to changes
zonemonthhour	Meteorology	Medium – state-submitted data likely, but do not expect significant variations from defaults

In A-84, this qualitative assessment led to a focus on five inputs thought to have the highest influence on national, annual emissions: vehicle miles travelled (VMT), vehicle population, age distribution, average speed and road type distribution. These became the “primary” inputs studied extensively through A-84. The state-submitted data for these inputs were analyzed and compared to MOVES defaults, and the sensitivity of MOVES emissions to variability in each assessed. From this a relative ranking of the influence of each input, by MOVES source type (vehicle class), was determined. This ranking, which varied by pollutant, is shown in Table 2. For HC and CO the top five most influential inputs were for car and light input trucks (passenger and commercial), for age distribution, population and VMT. Total emissions of these pollutants increased 20-30 percent when these inputs were varied from the 10th to 90th percent level. For NO_x and PM, VMT fraction and speed distributions were the

most influential, with combination long-haul truck VMT fraction having the largest influence; total NOx and PM emissions increased nearly 40 and 80 percent, respectively, when combination long-haul truck VMT fraction was increased from the 10th to 90th percentile level.

Table 2. Most Influential Inputs by Source Type / Cluster from A-84

HC		
Source Type/Cluster	Input Varied	Increase in Total Emissions
Passenger Car	Age Distribution	23.5%
Passenger Truck	Age Distribution	22.3%
Passenger Truck	Population Fraction	15.7%
Passenger Truck	VMT Fraction	13.9%
Passenger Car	Population Fraction	12.4%
CO		
Source Type/Cluster	Input Varied	Increase in Total Emissions
Passenger Truck	VMT Fraction	29.8%
Passenger Truck	Age Distribution	24.9%
Passenger Car	VMT Fraction	21.8%
Passenger Car	Age Distribution	21.3%
Light Commercial Truck	Population Fraction	10.8%
NOx		
Source Type/Cluster	Input Varied	Increase in Total Emissions
Combination Long Haul Truck	VMT Fraction	39.0%
Passenger Truck	VMT Fraction	21.5%
Combination Short Haul Truck	VMT Fraction	19.9%
Urban Unrestricted_Day	Average Speed Distribution	18.0%
Passenger Car	VMT Fraction	12.4%
PM		
Source Type/Cluster	Input Varied	Increase in Total Emissions
Combination Long Haul Truck	VMT Fraction	78.6%
Combination Short Haul Truck	VMT Fraction	34.7%
Urban Unrestricted_Day	Average Speed Distribution	18.3%
Rural Unrestricted_Day	Average Speed Distribution	14.0%
Combination Long Haul Truck	Age Distribution	12.7%

Table 2 pinpoints the MOVES CDM inputs that will have the biggest effect on total emission inventories if they are improved, at the source type level. This was a logical starting point for prioritizing the inputs to focus on improving for A-88.

3.2 CRC & EPA Priorities

In addition to A-84, the evaluation of potential Task 2 improvements also reflect stated priorities from CRC and EPA. From CRC, the request for proposals provided an initial list of project priorities, which were further defined in an email sent by CRC at the outside of the

project, which defined top priorities as “VMT mix ...(trucks versus cars for example)”, and “VMT by day of week”. It also provided input on EPA priorities, excerpts as follows:

“Items that help us estimate the quantity and spatial and temporal distribution of extended idling.”

“Speed distribution item is of lesser importance. We suggest replacing the speed item with an analysis of populations using the FHWA data. There is a lot of variability state to state in the ratio of VMT to vehicle population. This ratio affects starts and evaporative emissions.”

To clarify EPA’s priorities and plans for NEI updates, ERG coordinated a conference call with EPA/OTAQ and EPA/OAQPS modeling staff on February 6, 2014. During this call, EPA clarified that an analysis of population using the FHWA data was not necessary if direct population data (e.g. from state registration data) could be obtained. EPA also confirmed that prospects for improving start activity and the allocation of heavy-duty extended idle should be evaluated, as was improving temporal VMT distributions. Although the latter was judged in A-84 not to have much influence on annual emissions estimated in the NEI, EPA’s interest in improved temporal VMT distribution is for episodic modeling via the EPA air quality modeling platform.

3.3 Initial Screening

ERG then performed an initial screening of the most influential inputs from A-84 and priorities expressed by CRC and EPA to determine the feasibility for improving these inputs within the scope of A-88. The objective of this was to narrow down inputs that showed the most promise for carrying forward to Task 2. The initial screening was focused on the question of whether national datasets existed that could potentially improve local defaults, and whether they could be obtained within the timing and cost of the contract.

Of all of the inputs considered in this initial screening, only speed distribution did not meet the criteria, primarily because of cost. “Telematics” datasets are being compiled by a number of commercial entities including cellular providers and commercial GPS vendors, and are available for purchase, generally aggregated in such a way that no personal information can be retrieved. For example, on behalf of EPA, ERG worked with TomTom, Inc. to provide speed distribution data averaged across the entire U.S. to update the MOVES national defaults. Link-specific speed data is also compiled by INRIX, Inc. who provides real-time traffic data to mapping programs from telematics and other data sources. From this, we believe that telematics data will be an excellent source of data to improve local activity inputs for MOVES, and cost effective if pursued for individual areas. For example, ERG has had initial discussions with one

cellular company that compiles these data on behalf of insurance companies; these discussions have confirmed that data on speed distribution and a number of other trip-related activities are available by location across the U.S. For heavy trucks, telematics systems are increasingly used for fleet management, and can provide speed distribution data for long-haul trucks.² However, based on previous ERG work with telematics data, the projected cost of location-specific data for tens or potentially hundreds of specific locations around the U.S. was judged to be well beyond the scope of this contract. This, combined with EPA input that speed distribution as of low priority, led us to remove speed distribution from further consideration in A-88

3.4 “Short-List” Inputs Chosen for Detailed Evaluation

Based the initial assessments described in Section 2.1-2.3, ERG settled on the following “short list” inputs to move ahead for detailed evaluation:

- Passenger car & truck age distribution
- Passenger car & truck population
- Combination long-haul VMT
- Temporal VMT distribution (e.g. allocation of VMT by day & hour)
- Heavy-duty extended idling
- Vehicle start activity

A detailed evaluation was performed for each to identify viable datasets and an approach to update current defaults. These evaluations, along with a recommended approach for improving each, are presented in Section 4.

4.0 DETAILED EVALUATION OF “SHORT LIST” INPUTS

The detailed evaluation of the short-list inputs required assessing the data source of current defaults, identifying candidate data sources that could update the defaults, and determining how the data sources could best be used to improve current defaults. The focus was on datasets maintained at a national level, e.g. by federal agencies or companies focused on national data compilation, rather than states. The data sources should cover the entire U.S. while providing location-specific data for MOVES that would be an improvement to the current defaults. The results of the detailed evaluation for each input are discussed in the subsections below.

4.1 Passenger Car & Truck Age Distribution

Version 1 of the NEI used a combination of state-submitted age distribution data for ~1,400 counties and national defaults developed from a national compilation of state registration databases. To improve the age distribution data for the remainder of counties, ERG evaluated purchasing county-level data from the database of vehicle registrations compiled by IHS Automotive (formerly R.L. Polk). The source of these data are state vehicle registration databases, which is consistent with the approach in EPA MOVES guidance³ and the majority of states that compiled and submitted data in Version 1.⁴ The primary IHS database is focused on light vehicles, which would apply to MOVES passenger car, passenger truck and light commercial truck source types (source types 21, 31 and 32). The IHS database contains vehicle population to the county, model year, and vehicle make level. Age fractions can be derived from these data and be used directly for age distribution inputs for passenger cars, passenger trucks and light commercial trucks in MOVES. Purchasing and deriving age distribution data from IHS for passenger cars and trucks is a straightforward way to improve the default age distribution data. County-specific distributions are a significant improvement over the national default age distributions currently used in MOVES, and based on the results of A-84 would have a meaningful effect on emissions. The cost of purchasing the IHS data is relatively modest, and would be a good ongoing investment for the emission inventory and air quality community to make. Taking all of these factors into account, ERG recommended that updates to age distribution defaults based on county-level IHS data be undertaken as part of the A-88 project.

4.2 Passenger Car & Truck Age Populations

For Version 1 NEI, default vehicle population data were calculated using annual miles per vehicle applied to default VMT estimates. For A-88, the IHS database was also evaluated as a source for updated default county-level passenger car & light truck vehicle populations. With this approach, the same model-year based populations used for age distribution would simply be totaled by county separately for passenger cars and light trucks, by fuel type. The IHS car population numbers by county can be fed directly into MOVES county database estimates for passenger cars (source type 21); with additional needed to split between the two light truck source types. Because the data purchased through IHS can be readily used for vehicle population as well as age distribution, ERG recommended that county-level population data for all U.S. counties also be derived from the data purchased from IHS.

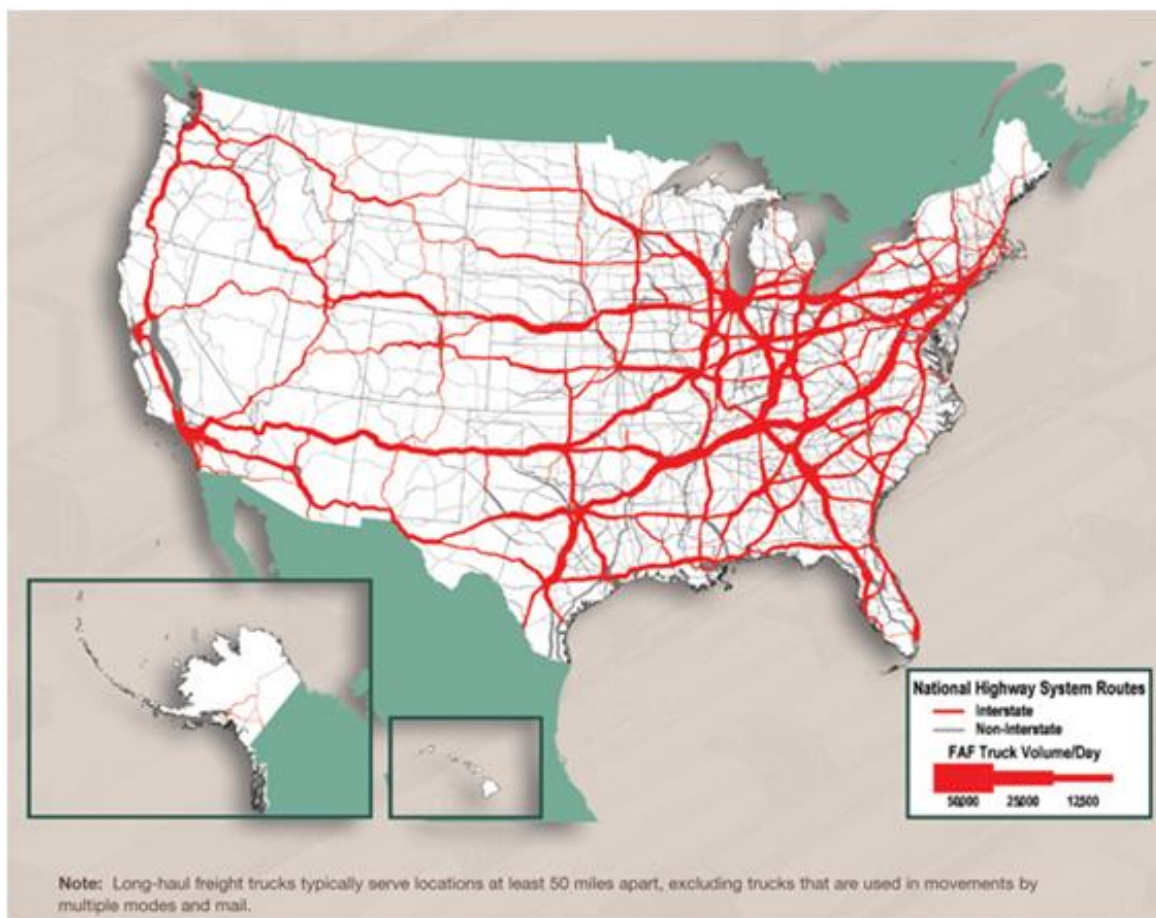
4.3 Long-Haul Truck VMT

For Version 1 NEI, default long-haul truck VMT were developed directly from the 2011 HPMS county data for single unit and combination trucks, combined with national defaults

allocating these to the long- and short-haul categories. The national default long haul allocations were derived from VIUS2002 and apply uniformly across the entire country.⁵ Because the HPMS county data is the main repository of local VMT estimates across the nation, it was considered the best national source of local-specific VMT data; however, HPMS only reports totals in the single unit truck and combination truck classifications, not broken down by short-haul vs. long-haul, or fuel type. A key opportunity for improving NEI default VMT estimates is therefore in the allocation of HPMS VMT into these subcategories, particularly for long-haul trucks.

ERG evaluated the Freight Analysis Framework (FAF), a compendium of data and analyses maintained by FHWA, as a candidate source for updating long-haul truck VMT allocations.⁶ The FAF integrates information from a number of transportation and commodity flow data sources to allow a more detailed assessment of travel and population related to goods movement in each U.S. county. Included in the FAF are data on average annual daily traffic (AADT) for long haul trucks reported for specific segments of interstates, highways and major roads across the U.S. (Figure 2).

Figure 2. FAF Average Daily Long-Haul Freight Traffic (Source: FHWA)

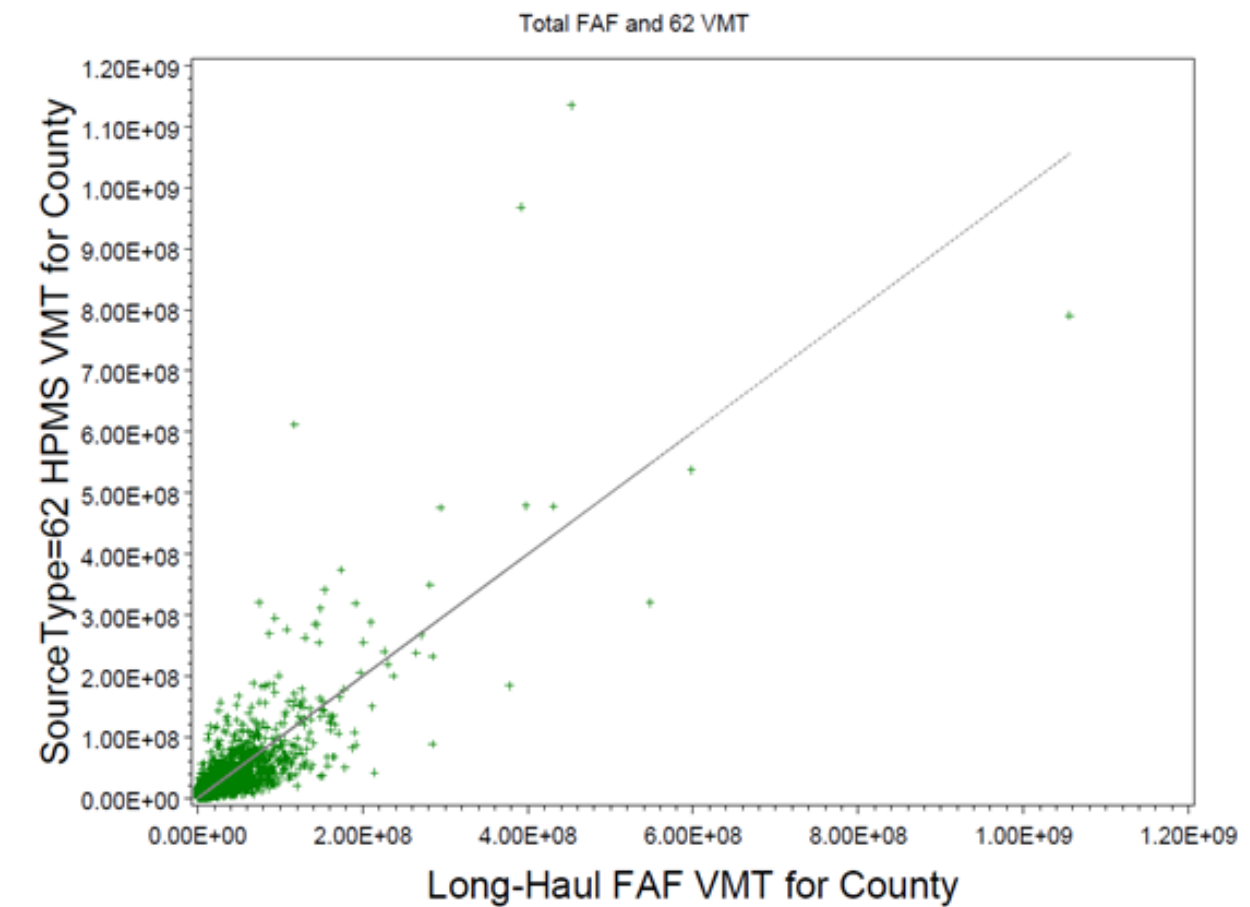


ERG evaluated the FAF and confirmed it to be the only database focused on quantifying long-haul truck travel by specific geographic location at a national level. Previous research on heavy-duty telematics datasets demonstrates that it could provide such information in time, but as of yet do not appear to provide the needed coverage for a geographic national scale.⁷

Although the FAF holds promise for improving long-haul truck VMT estimates, there are several caveats that need to be considered in determining how to apply the data for location-specific emissions modeling. The primary caveat is that FAF long-haul truck volumes are not based on direct measurement, but are modeled from a series of estimates of network capacity, commodity flow and truck trip lengths. The FAF estimates of total truck volumes are validated against measured vehicle counts in aggregate, though the FAF documentation cautions the user on the accuracy of the estimates at a fine level of detail, e.g. on any given network link.⁸ Additional caveats are that the FAF only covers a subset of interstates and major roadways, and the FAF is only updated in accordance with the five-year cycle of the U.S. Economic Census, with the most recent year of complete data being 2007. For these reasons, ERG recommended that the FAF estimates be used to inform the relative contribution of long-haul trucks to current 2011 VMT estimates, rather than using direct estimates of FAF long-haul VMT to replace the 2011 estimates.

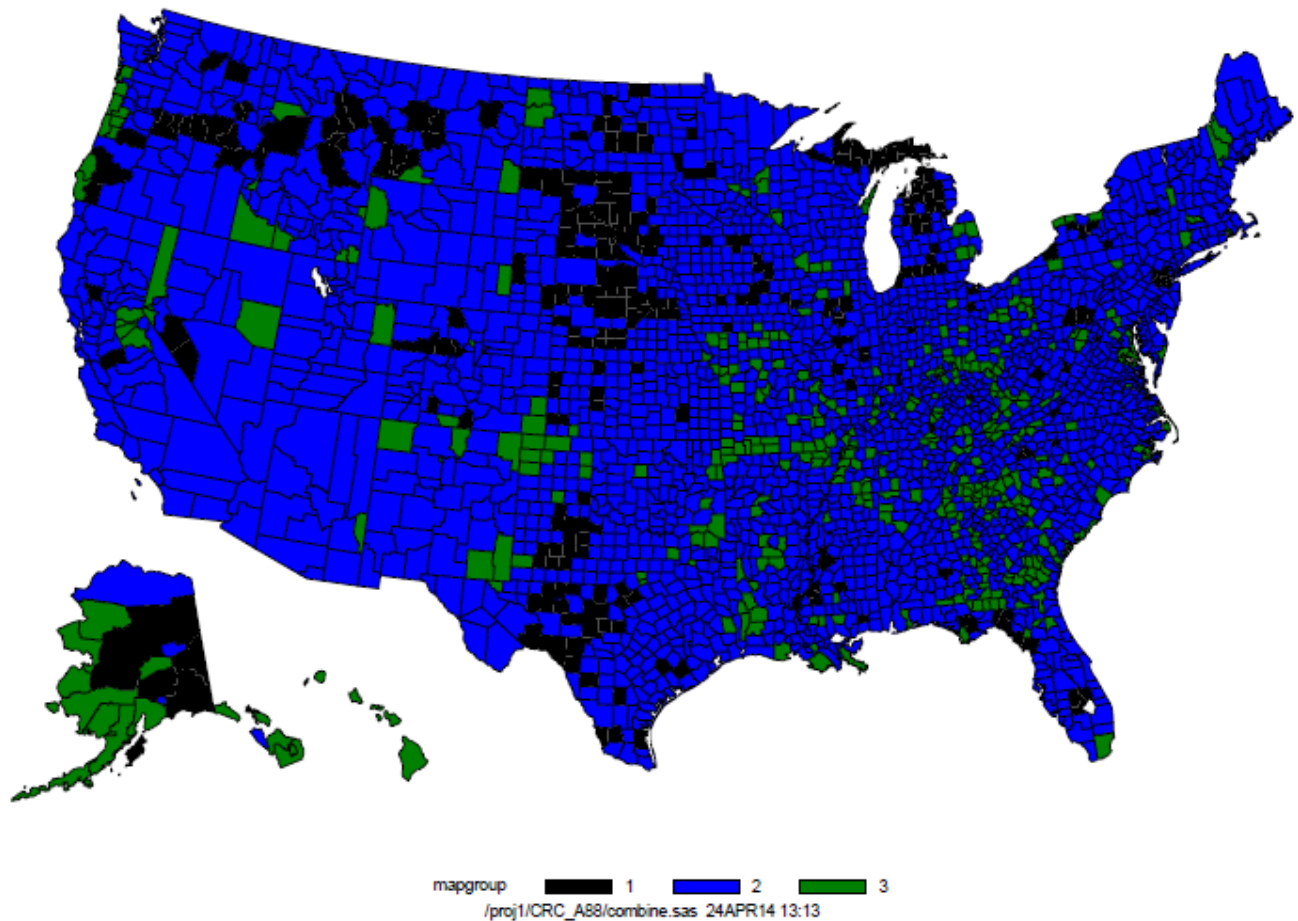
As a general check, ERG evaluated FAF long-haul VMT estimates against national default VMT used in Version 1. Figure 3 shows a comparison of 2007 FAF long-haul truck VMT (x-axis) vs. NEI default 2011 VMT, split into the MOVES combination long-haul source type (y axis), which travel mostly on the major roads covered in the FAF. Each point represents a single county, with a 1:1 line superimposed to show the relative scatter of the data. This plot highlights the high degree of difference between FAF and default on a county-specific basis; many counties show a relative difference of a factor of five or more vs. the default. Based on the A-84 results, this level of variability in long-haul VMT would have dramatic effects on total PM and NOx emissions.

Figure 3. FAF Long-Haul VMT vs. Default VMT by County



The CRC panel requested a mapping of FAF vs. default data to understand geographic trends. To address this request, the same data are also represented in Figure 4 below. This map shows very broad groupings of “FAF > 3x default” (black), “0.33x default < FAF < 3x default” (blue), and “FAF < 0.33x default” (green). This shows where the extreme values from Figure 3 are located. The map shows that the more extreme differences between FAF and default long-haul VMT (black and green counties) are spread across the country, and seem to be in rural areas as opposed to major cities.

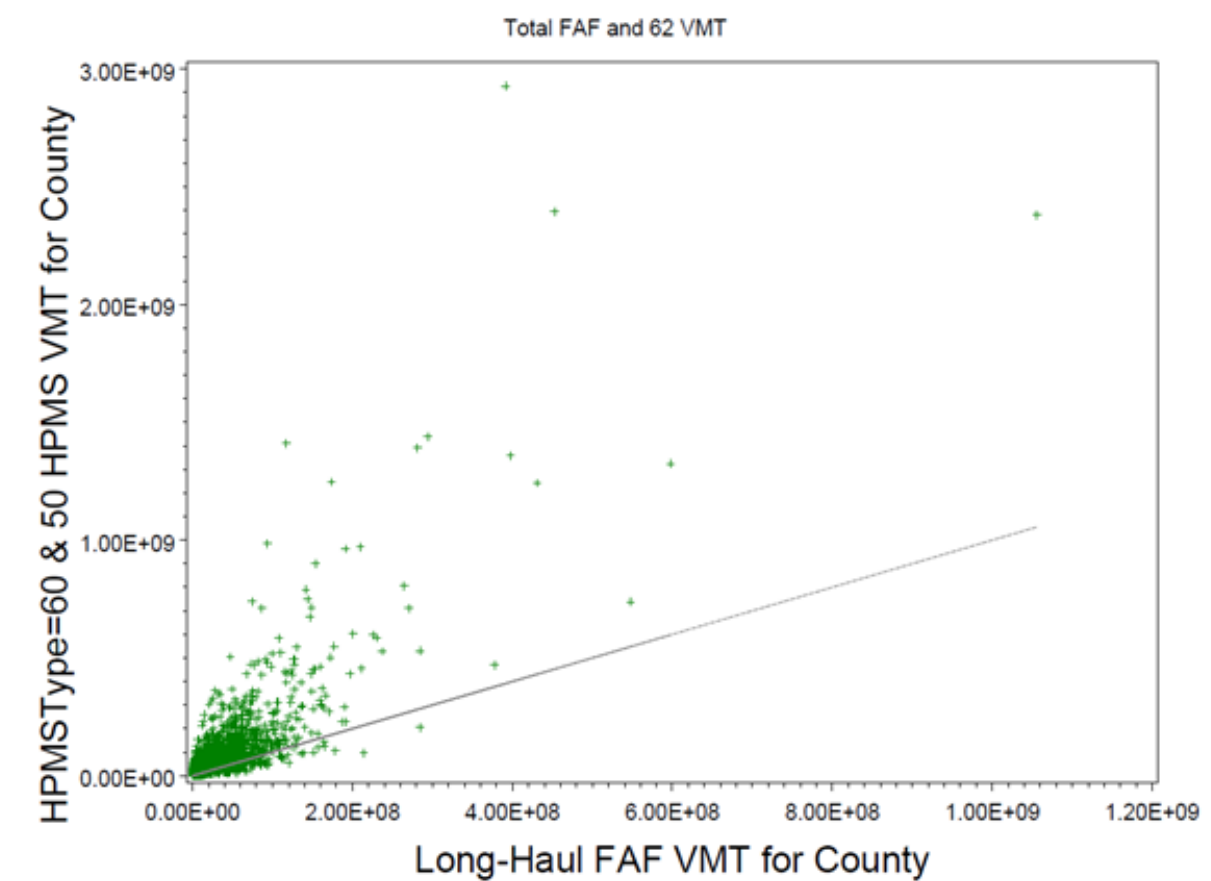
Figure 4. FAF Long-Haul VMT vs. Default 62 VMT by County – Extreme Differences (Black = extreme high, Green = extreme low, Blue = not extreme)



Given the wide spread of FAF estimates compared to defaults, a further reasonableness check was performed against more direct HPMS estimates. While HPMS does not estimate long-haul trucks directly, it does provide direct estimates for single unit and combination trucks. Although the exact percentage is uncertain, all trucks considered long-haul will fit within these HPMS single unit or combination categories; according to both FAF and MOVES default estimates, about 10 percent of long haul trucks are single unit. FAF long-haul VMT was therefore expected to be less than HPMS single unit + combination truck VMT for each county. This comparison by county is shown in Figure 5, with a 1:1 line superimposed. In the majority of counties, FAF long-haul VMT is lower than HPMS single unit + combination as expected, but does appear higher for some counties. This underscored the need for caution in applying the

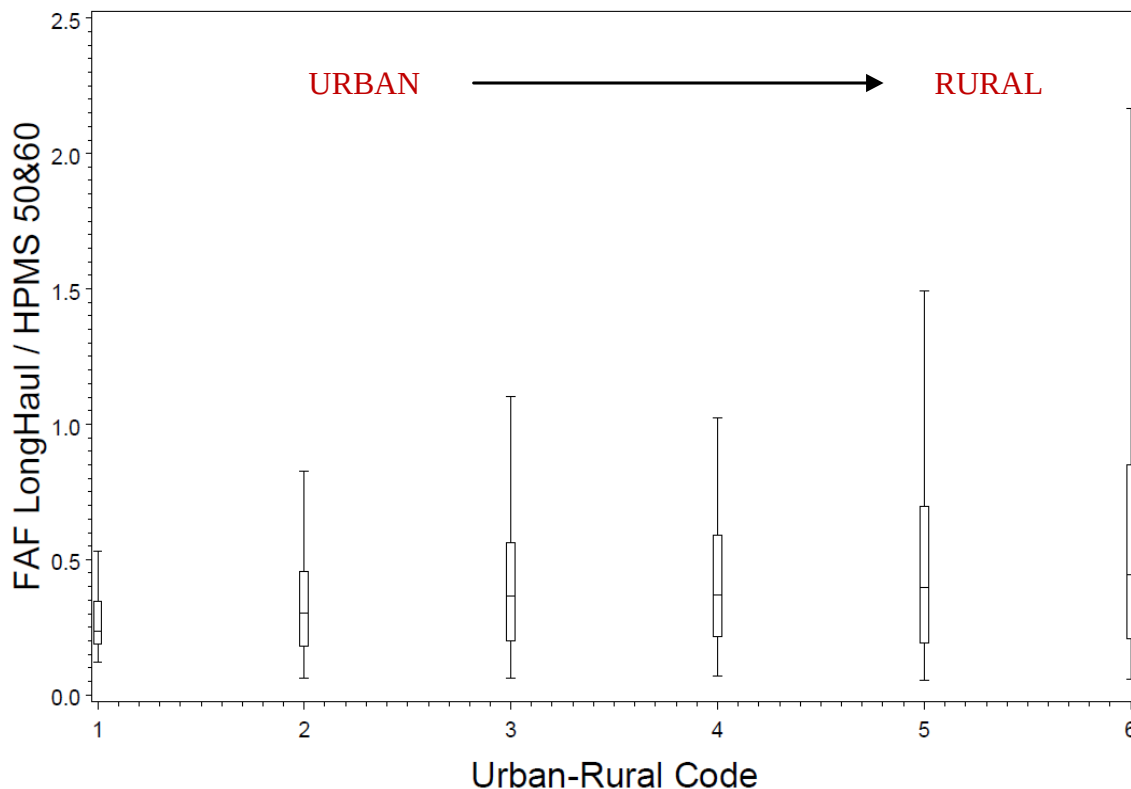
FAF at the county level, and pointed to the need for regional aggregation of FAF estimates to reduce the influence of more extreme county-level values.

Figure 5. FAF Long-Haul VMT vs. Total HPMS Truck VMT by County



ERG investigated reasons behind the variability in FAF long-haul VMT vs. total single unit+combination VMT, particularly for counties which showed higher FAF long-haul estimates than the HPMS superset. ERG binned each county according to a 6-level urban/rural classification code used by the CDC National Center for Health Statistics (1=large central metro, i.e. most urban; 6 = non-core, i.e. most rural) and looked at the spread in the ratio of FAF long-haul: HPMS single + combination VMT in each. This is shown in Figure 6, with box plots by each urban/rural code (whiskers are 5th/95th percentile). This shows that the ratio of long-haul truck VMT to HPMS single+combination truck VMT is higher in more rural counties, with the values greater than 1 (i.e. below the 1:1 line in Figure 5) generally falling in the most rural counties. This initial screening provided insight into ways to aggregate county-level FAF estimates to smooth out the noise of individual county extremes, and the influence of urban vs. rural areas on long-haul truck traffic.

Figure 6. Spread of FAF Long-Haul: HPMS Single + Comb. VMT Ratio by Urban/Rural Level



Given the overall dearth of information on long-haul vs. short-haul truck VMT mix, the FAF was judged to be a viable national dataset for improving long-haul truck VMT by introducing a regional component. Because of the caveats listed, however, the use of FAF was focused on allocation of 2011 HPMS VMT, rather than for direct replacement of VMT values.

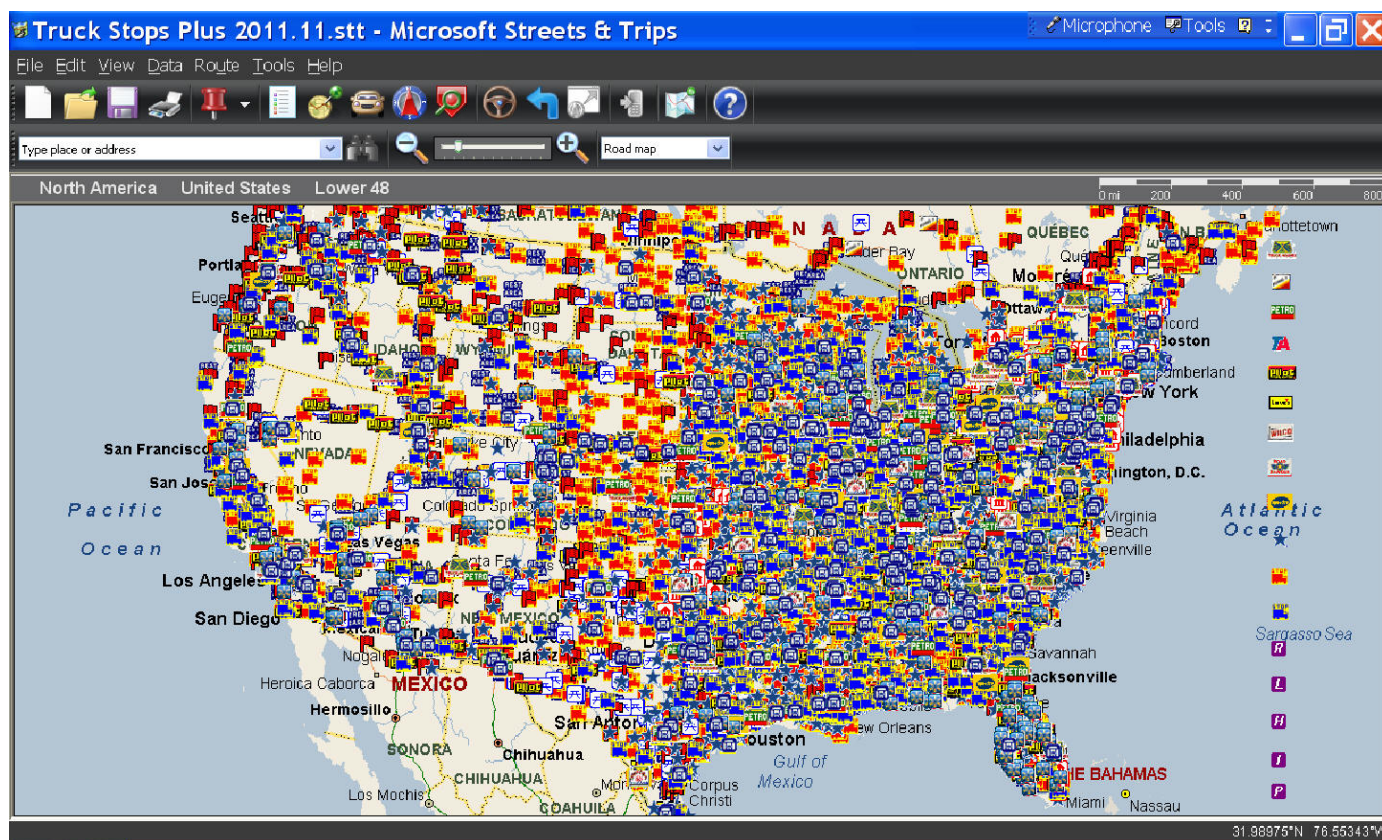
4.4 Heavy-Duty Truck Idling

At the outset of the project, CRC and EPA indicated a desire for improved information on the quantity and spatial/temporal allocation of extended heavy-duty truck idling emissions. This would serve not just the NEI but inventory and air quality modeling by EPA, regional and local modelers. National datasets that can establish location-specific inputs for total idle activity do not yet exist. Heavy-duty telematics may provide these data in time, but coverage is currently not broad enough. ERG's evaluation of heavy-duty idling for A-88 therefore focused on data that could improve the spatial distribution of idling activity and emissions, rather than the quantity. ERG evaluated four such databases for use in the analysis: 1) Truck Stops Plus (truckstopsplus.com), 2) Truck Stop Report (truckstopreport.com), 3) Truck Stop Pro (truckstoppro.com), and 4) POI Megafire (msstreets.com). For this evaluation, ERG concluded that the commercially available database Truck Stops Plus provides the most comprehensive and

detailed database for the analysis, at a nominal cost (approximately \$40).⁹ The database contains over 7,300 trucks stops and includes all major chain truck stops, as well as independent truck stops (Figure 7). This dataset includes the size category of each truck stop (less than 20 parking spaces, 20-70 parking spaces, and more than 70 parking spaces), and details such as whether or parking is allowed, whether there is a charge for overnight parking, and what services and facilities (e.g. showers) are offered. These data were deemed useful in determining the relative amount of idling at any given location. However, because of similar efforts being undertaken by EPA and states, CRC ultimately decided not to pursue further development of heavy-duty idle allocations beyond this initial evaluation of the truck stop database. To aid in the related work of EPA and states, ERG delivered the cleaned, geocoded database as part of the A-88 deliverables.

ERG purchased the Truck Stop Plus database as part of Task 1 evaluation, and performed some cleanup of the database to enable further analysis. Although this work was not continued in Task 2, CRC requested that ERG deliver the cleaned-up database to aid in QA of related work that states and EPA are undertaking.

Figure 7. Truck Stop Locations from Truck Stop Plus



4.5 Vehicle Start Activity

Although not a direct MOVES input for the NEI, CRC and EPA requested an evaluation of whether improved information start activity at the local level could be developed. Start activity data is currently calculated from individual vehicle constructed from instrumented vehicle studies conducted in several cities around the U.S., providing key-on and key-off times for each vehicle trip on an individual vehicle basis. This provides a consistent activity basis for start and park activity needed for start as well as evaporative emissions processes. National default estimates of starts/vehicle and soak distribution are aggregated from this collection of driver surveys.

While telematics data holds promise for improving local estimates of start activity in MOVES, ERG concluded that coverage and cost precluded it from being used to develop local default start activity across the nation under A-88. ERG therefore focused on the most viable national source for trip activity data, the National Household Travel Survey (NHTS).¹⁰ The NHTS is conducted every several years by FHWA (update cycles in the past few decades have ranged from 5-8 years), and compiles extensive data on vehicle trip activity for individual households (e.g. trips per household, trip length, trip time of day) by location across the U.S. based on surveys. While this focuses on the travel of passenger vehicles, these vehicles have been shown to produce the majority of overall start emissions in inventory. An investigation of using the NHTS for updating MOVES soak distribution has already appeared in the literature, though this was for national distributions.¹¹

For A-88, ERG evaluated the most recent NHTS trip database (2009) with a focus on whether there are detectable variations in start activity in specific locations that could translate into location-specific defaults. ERG's evaluation of the NHTS trip data focused on calculating starts activities in the form of MOVES start activity, with a focus on determining if starts behavior varied substantially by some geographical measure, focused on weekday passenger cars trips. Default MOVES estimates show a total number of starts per vehicle of 5.88 starts per day. By comparison, ERG calculated the average number of trips/vehicle/day for the NHTS dataset as 2.73. This significant discrepancy raised the question of whether trip surveys used as the basis for NHTS underreport the actual number of key-on starts represented by MOVES, and whether NHTS overestimates the number of zero-trip vehicles because it focuses on a single day of household activity. ERG's analysis found that 34 percent of the vehicles in the NHTS dataset had zero trips, which has a major effect on the trip/day averages presented here. How representative this prevalence of zero-trip vehicles are in the entire population is a significant question that would require resolution before applying NHTS data in MOVES.

Although there are questions about how well NHTS could be used to estimate absolute start/day estimates in MOVES, it does provided a good dataset for exploring geographic differences in trip activity. ERG analyzed how trips/vehicle vary by geographic region, analyzing trips/vehicle by broad census divisions in the country (Table 3), where trips/vehicle ranged from 2.63 to 2.87; by state, with a range of 2.54 to 3.21, and by metropolitan area (“core-based statistical area”, or CBSA), with a range of 2.44 to 3.26. The NHTS dataset also included an Urban/Rural variable, assigned to every household. The rural vehicles averaged 2.48 trips/vehicle/day and the urban vehicles averaged 2.82 trips/vehicle/day. The wide spread of these two values is almost as wide as the spread of the fifty values by state or CBSA. This perhaps unexpectedly wide spread in average trips/vehicle/day is understandable in terms of differences in human/vehicle behavior in urban vs. rural geographical areas. It suggests that a factor like urban vs. rural or a factor that influences vehicle behavior might be helpful in stratifying the vehicle start distribution for more accurate emissions estimates by MOVES.

Table 3. Trips/Vehicle/Day by Census Division (raw data)

Census Division	Number of Vehicles	Average Trips/Vehicle/Day
EastSouthCentral	2343	2.63
SouthAtlantic	39804	2.65
Pacific	17248	2.66
NewEngland	2284	2.78
WestSouthCentral	14192	2.80
EastNorthCentral	5264	2.80
MiddleAtlantic	12385	2.82
WestNorthCentral	5823	2.85
Mountain	5979	2.87

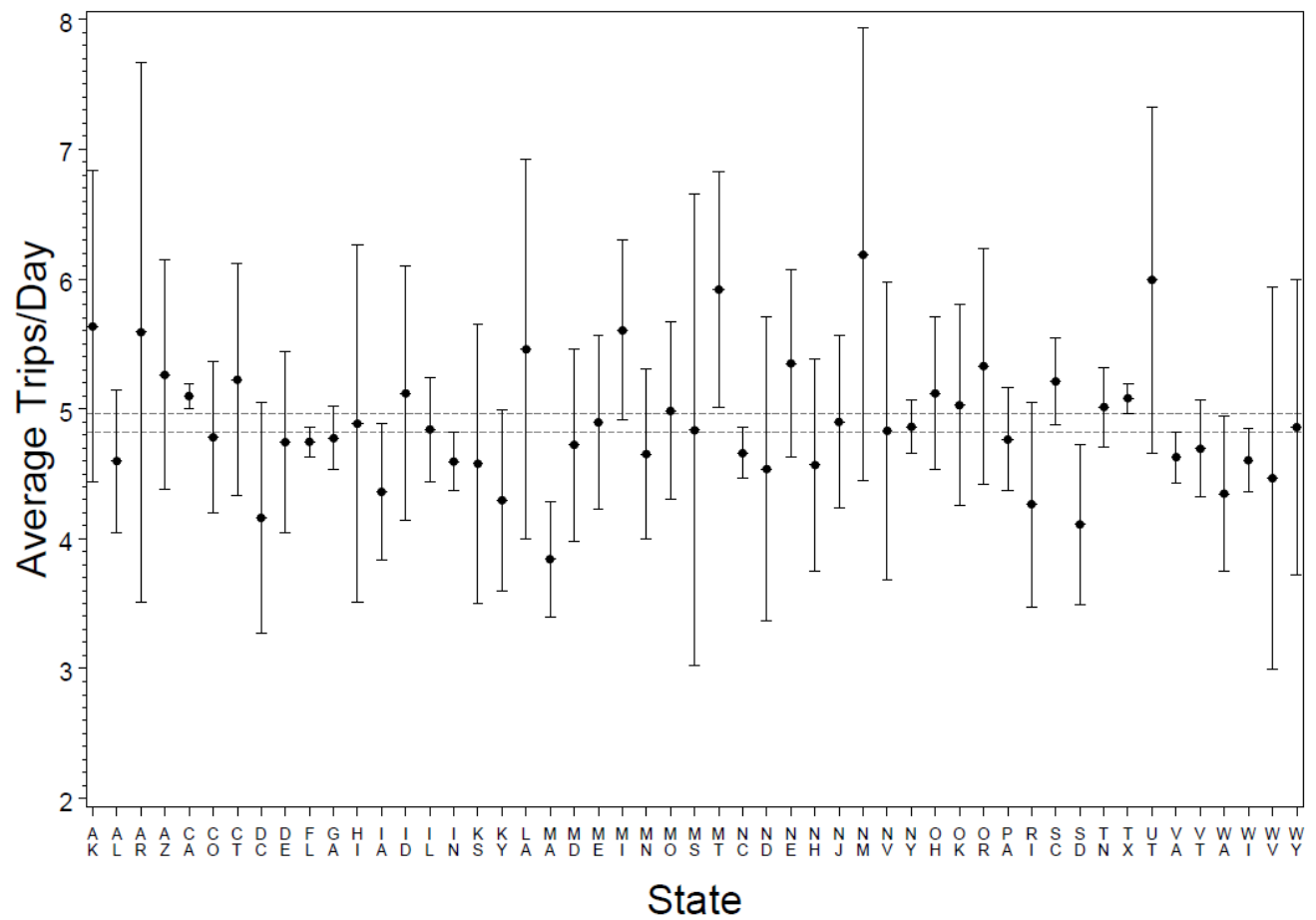
These results did not consider weighting factors that NHTS provides to account for the stratifications in the sample, and as mentioned, ERG’s judgment was that the proportion of zero-trip vehicles is overstated in these results. Further analysis was therefore performed on a sample that excluded all vehicles with zero-trip days, and that used the NHTS weighting factors. When these changes were made, the average trips/vehicle/day was 4.9 trips/vehicle/day – much closer to the MOVES default of 5.9.

Figure 8 shows the 95 percent confidence limits on the average trips/vehicle/day by state for passenger cars on weekdays, with zero trip vehicles removed and corrected for stratification using the NHTS weighting factors. The horizontal lines give the 95 percent confidence limits for the national average. If an error bar for a geographical area does not cross at least one of the national horizontal lines, then the average trips/vehicle/day for the area is significantly different from the national average at the 95 percent confidence level. At the 95 percent confidence level

about 5 percent of the areas would be expected to appear to be different from the national average by chance alone. Figure 8 shows that averages CA and MT are higher and MA and SD are lower than the national average. Since there are 50 states, we would expect 2.5 states to appear to be different by chance alone; therefore, since four states (8 percent) appear to be different from the national average, there may be a real effect of state present.

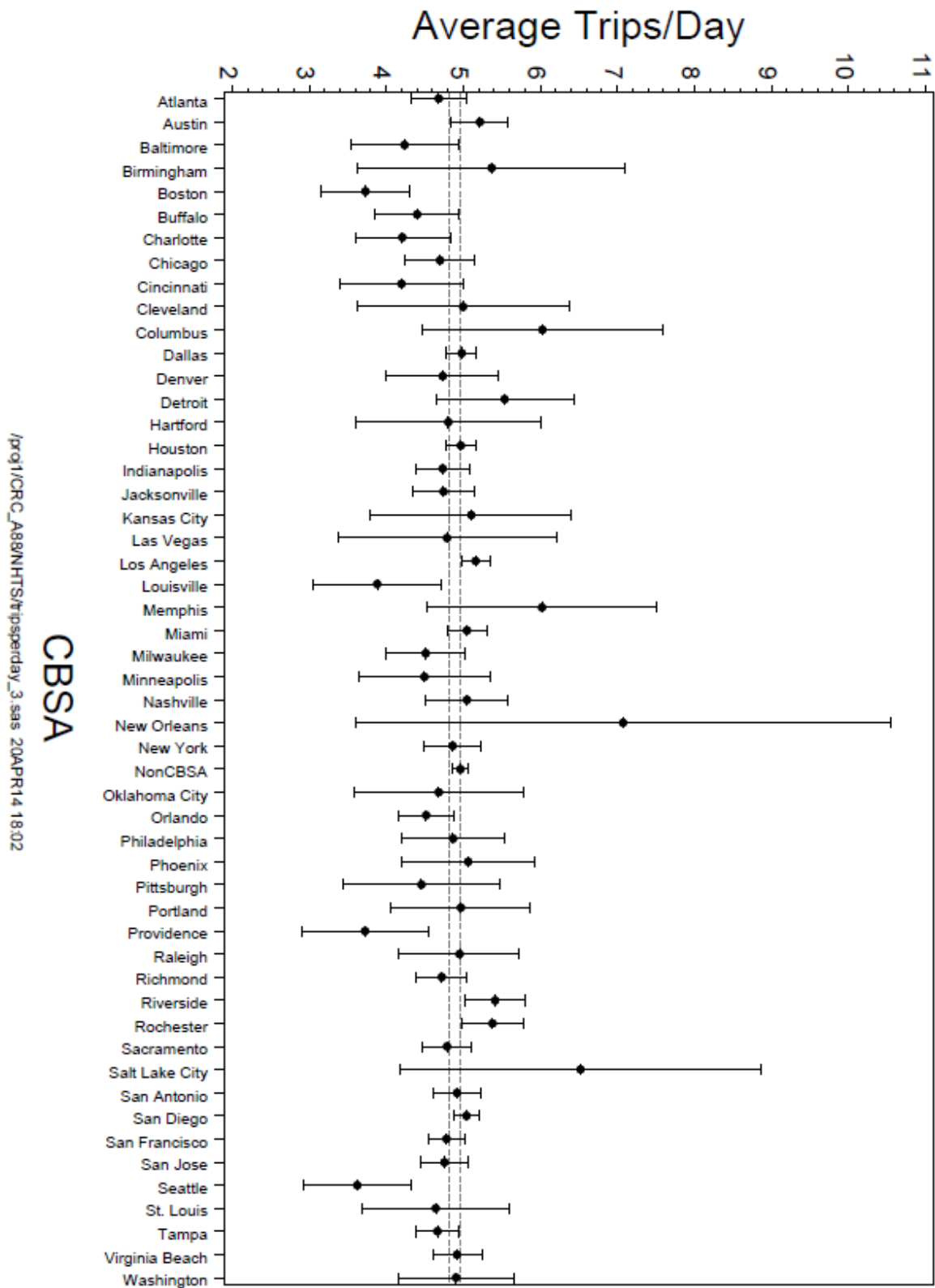
Figure 9 shows a similar analysis of the 51 CBSA areas. Most CBSAs have urban and rural areas. The averages for Riverside are higher and Boston, Louisville, Providence, and Seattle are lower than the national average. We would expect 2.5 CBSAs to appear to be different by chance alone. Therefore, since five CBSAs (10 percent) appear to be different from the national average, there may be a real effect of CBSA present. A further analysis was performed for a group of 200 areas defined by splitting CBSAs into urban and rural areas. The averages for 6 areas are larger and for 21 areas are lower than the national average. We would expect 10 areas to appear to be different by chance alone. Therefore, since 27 areas (13 percent) appear to be different from the national average, there may be a real effect of urban/rural area present. Overall, even though there is concern with using NHTS data directly in MOVES because of the zero-trip vehicle issue, an evaluation of the effect of geographical area on trips/vehicle/day indicates that there is a statistically significant observable effect using only the vehicle that did make trips.

Figure 8. Average Trips per Day, By State (zero trip vehicles removed)



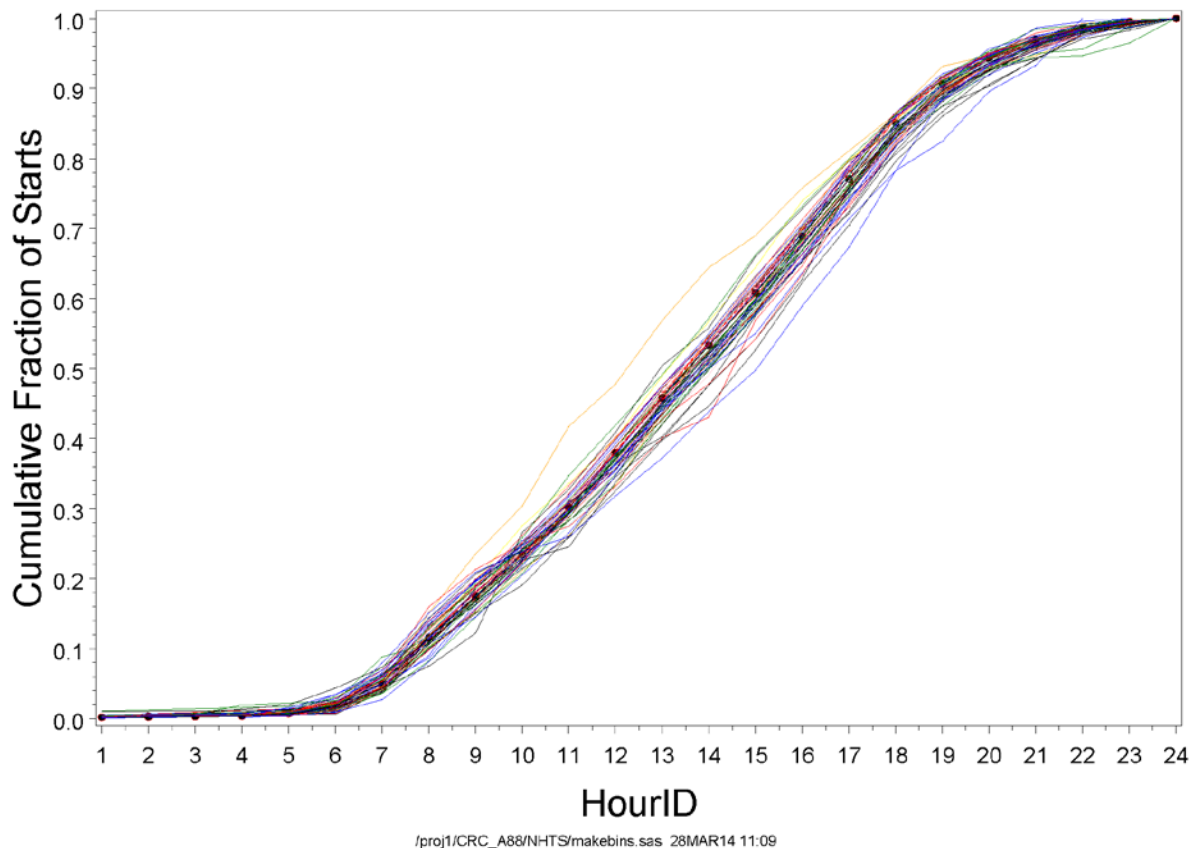
/proj1/CRC_A88/NHTS/tripsperday_3.sas 20APR14 18:02

Figure 9. Average Trips per Day, by CBSA (zero trip vehicles removed)



The distribution of starts/vehicle/day among the 24 hours in the day also has an effect on emissions. To examine this, ERG looked at the effect of geography on the cumulative relative fraction of trips by hour in the NHTS database, which is characterized as soak distribution (or operating mode distribution for the start emission process) in MOVES (Figure 10). This analysis demonstrates that there is a range of trip patterns by time of day across different metro areas; for example, the point at which half of the trips in a household ranged from noon to 4pm.

Figure 10. Cumulative Fraction of Trips by Hour of Day, by CBSA



In general, NHTS may be a viable data source to improve location-specific MOVES starts/vehicle, temporal allocation, and soak distribution. However, there are some significant questions about how well NHTS trip survey data represents key-on start events needed by MOVES. For this reason, the project team decided not to pursue updates to start activity under A-88. For future consideration, the next iteration of NHTS will include GPS-equipped vehicles, which should address the primary questions of reported trips vs. actual key-on events. This may make NHTS a more viable source for start activity in the future.

4.6 Temporal Distribution of VMT

A discussion of Temporal VMT distribution was included as part of Task 1, with a recommendation not to pursue this work under Task 2. Though there are temporal allocations in MOVES CDBs (DayVMTFraction, HourVMTFraction), SMOKE has separate temporal allocation factors that are applied to aggregate VMT. National defaults from FHWA studies conducted in the 1990s are the basis of the daily and hourly VMT allocations in MOVES. These defaults were developed from analysis of state-level traffic count data. The Vehicle Travel Information System (VTRIS) is a database of location and time-resolved state-level traffic count data compiled by FHWA. These data can provide the exact input needed for daily or hourly VMT allocation in MOVES and/or SMOKE. Unfortunately, data is only collected and maintained in VTRIS for 27 states; updating for just these states would still be a significant improvement over national defaults. Under a separate NCHRP project (NCHRP 25-38), ERG is working with Cambridge Systematics to develop resources and data tools for MOVES practitioners. As part of this work, Cambridge Systematics is developing a spreadsheet tool that compiled VTRIS data and provides VMT allocation data at the level needed by MOVES. The project will be complete, and tool available to users, anticipated by Fall 2014. Because the VTRIS tool compiled for NCHRP 25-38 is imminent, and because temporal allocation of VMT is desired not for NEI improvement as much as broader (and perhaps longer term) episodic air quality modeling, ERG recommended (and the CRC panel agreed) to not pursue temporal VMT as part of the A-88 updates.

5.0 DEVELOPMENT OF IMPROVED LOCAL DEFAULT INPUTS

Based on the evaluations discussed in Sections 3 and 4 and input from the CRC A-88 panel, ERG proceeded with updating local default inputs for car and light truck populations and age distribution, and long-haul VMT fraction for combination and single-unit trucks. The methods and results of these updates are summarized in this section.

5.1 Car & Light Truck Age Distribution and Population

Car and light truck age distributions and populations were derived from vehicle count data by county and model year (for models years 1981 through 2012) as of July 1 2011, purchased from IHS. IHS compiled and processed the data from state vehicle registration databases, producing a dataset of vehicle counts separately for cars and light trucks (defined as <10,001 lbs Gross Vehicle Weight Rating). ERG derived age distribution from the IHS vehicle count data by converting into relative age distributions that sum to one (1) over 31 age categories from 0 to 30 years old. The cumulative distributions for each county are shown for cars and trucks in Figures 11 and 12. The resulting average vehicle age by county for cars and light

trucks is shown in Figures 13 and 14. For both cars and trucks, the average age ranges from 4 to 16 years; by comparison, the national MOVES default is 9 years. Based on the results of A-84, this spread in age distribution will have a significant influence on emissions, particularly HC and CO.

Figure 11. Cumulative Car Age Distribution by County

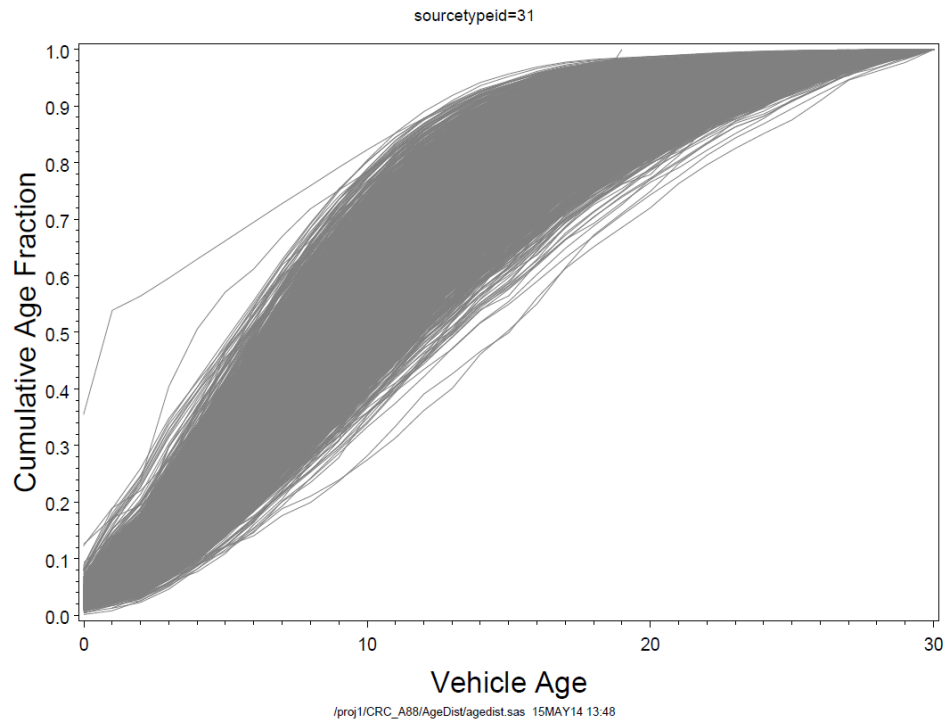


Figure 12. Cumulative Light Truck Age Distribution by County

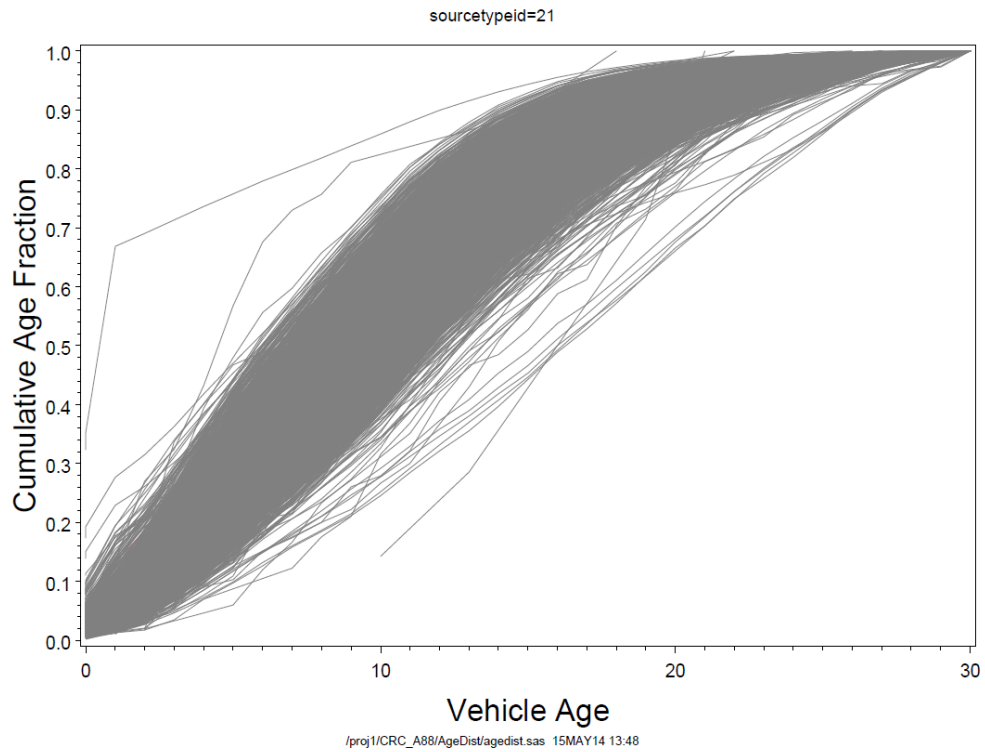


Figure 13. Average Passenger Car Age by County, 2011

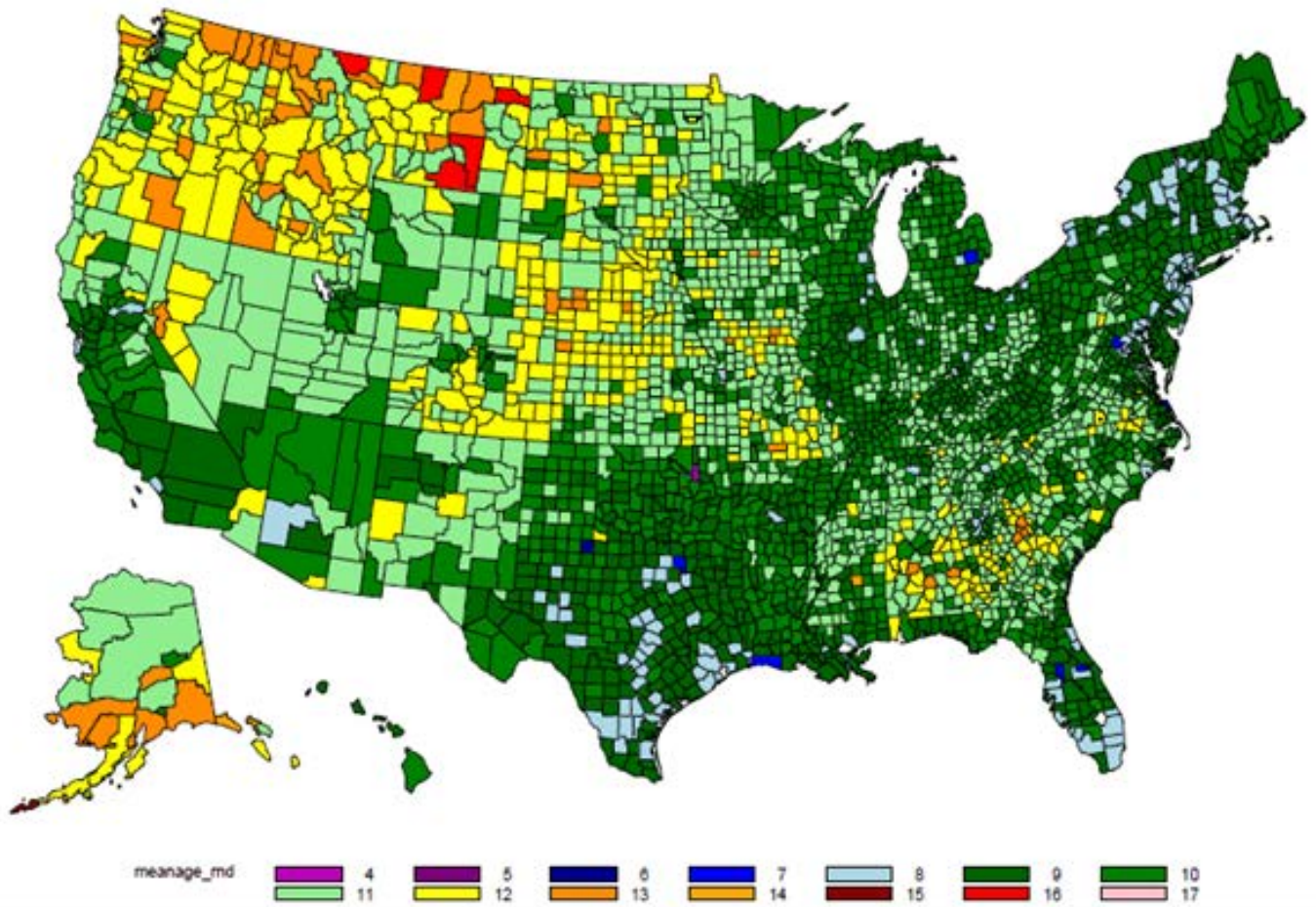
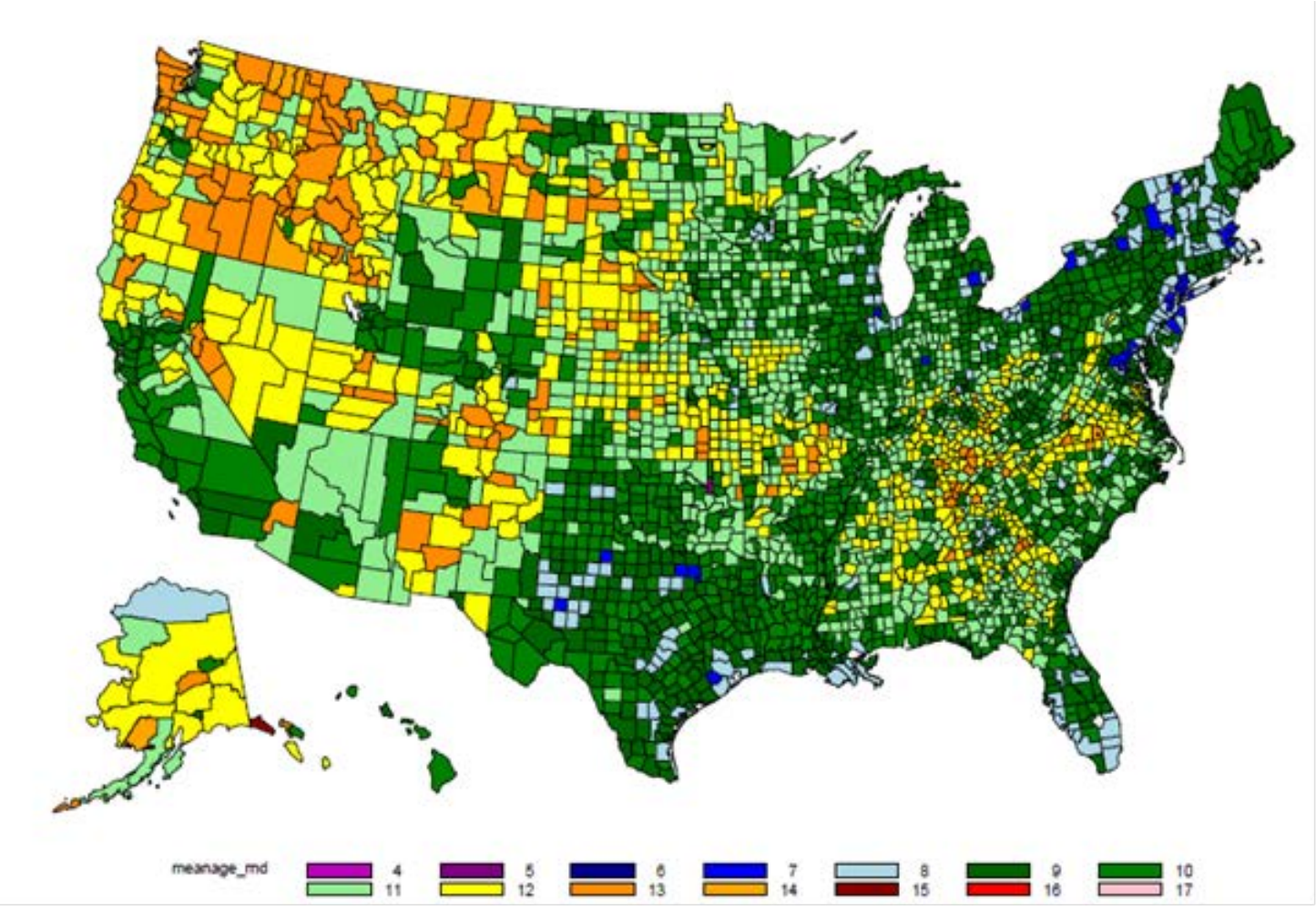


Figure 14. Average Light Truck Age By County, 2011



An issue identified with the IHS data is that it did not include vehicles for model years 1980 or earlier, as these model years lacked a standardized Vehicle Identification Number (VIN) schema. Following initial delivery of the derived age distribution and population data, the CRC A-88 panel conducted an analysis of state-provided percents of car and truck fleets that are age 30 and older and determined the median values were 2.25 percent and 0.6 percent, respectively, for cars and trucks. In order to remain conservative and avoid over-correcting the IHS data, the CRC A-88 panel specified these data were to be used as a floor; counties where the oldest age category already exceeded the 2.25 percent and 0.6 percent should not change. ERG implemented this correction to account for missing vehicles in a stepwise process. First, the counties whose vehicle age distributions contained age 30 proportions of the fleet below the proposed thresholds were flagged for further adjustment. Most counties were flagged for the adjustment; only two counties' car age distributions exceeded 2.25 percent in the raw data and 385 counties' truck age distributions exceeded 0.6 percent. The next step was to add vehicle population to the age 30 category until it comprised 2.25 percent of the total. Similarly truck population was added the age 30 category such that it became 0.6 percent of the fleet total. The final step was to normalize the revised populations by county and age ID, by dividing each model year population by the county total population, so that the car and light truck age distributions sum to one within each county. For the NEI, the age distributions derived from the IHS car data will apply to source type 21 (Passenger Car), and the light truck age distributions will apply to both source types 31 (Passenger Truck) and 32 (Light Commercial Truck).

Vehicle population was summed directly from the revised IHS data by county into the MOVES passenger car, passenger truck and light commercial truck source types. This was a straightforward aggregation of the revised IHS vehicle counts. IHS light truck populations by county correspond to total light trucks (passenger and light commercial, source types 31 and 32); for each county, ERG split the light truck totals into passenger trucks and light commercial trucks (source types 31 and 32) using the MOVES national default population splits between these source types, approximately a 75/25 split. The nationwide impact of increasing the pre-1981 car and truck populations was an overall increase in these populations by 2.15 percent and 0.4 percent, respectively.

Once adjusted, ERG delivered age distributions and populations for passenger cars, passenger trucks and light commercial trucks to CRC on July 25, 2014 for all 3,222 U.S. counties, in MS Excel spreadsheets.

After delivery of the age distribution and population data, the air agencies from two states reported differences between the IHS-derived age data and their own state DMV data, hypothesizing that they could be due to the presence of expired registration records in the IHS dataset, or errors introduced in processing of the data by IHS. To address these concerns, ERG followed up with IHS to clarify the source of the state-level data and IHS' processing procedure. IHS confirmed that their database is populated directly by state DMV data provided on a monthly basis, and that IHS does not do any additional processing of these data (other than adding "unknown" to missing fields) once received. ERG also did an independent comparison of the IHS-derived age distribution and population data with data provided in Version 1 of the NEI for each county in four randomly chosen states, and found generally good agreement for two (Minnesota and Utah), mixed results for one (Alaska) and more systematic differences for one (Pennsylvania). From discussion with IHS and this spot check of four states, ERG concludes that there are no errors or systematic differences introduced by IHS, as IHS is simply reporting what is provided to them by state DMVs. However, differences could appear between the IHS data and state air agency processing of registration data (i.e. for use in MOVES and/or submission to the NEI) if the air agency is using data that differs from what their DMV provided to IHS.

5.2 Long Haul Truck VMT Fraction

Long Haul VMT fractions were developed as a means to allocate 2011 HPMS VMT by county developed for Version 1 of the NEI or provided directly by states. The fractions were developed based on comparisons of FAF and HPMS VMT data. The two datasets provide estimates on roughly the same network in the U.S. (interstate, other freeway/expressway and principle arterial). FAF provides estimates of long-haul AADT and VMT and total VMT for individual road links, while HPMS data provides estimates of single unit & combination truck AADT and VMT for individual road links, as well as total AADT and VMT. Direct comparison of the FAF and HPMS data proved difficult because of the datasets are from different years, and because individual roadway links could not be matched between the two datasets. The focus therefore fell on interstates at the county level, which could be matched up in the two datasets. A comparison of interstate road mileage in the FAF dataset with interstate road mileage in the HPMS dataset matched by county, giving confidence that the FAF and HPMS data were on the same basis. All other roads were grouped as "non-interstate" for analysis. A check of FHWA Highway Statistics shows that that the majority of non-interstate VMT is on principal arterials, i.e. unrestricted roads. In application to MOVES and NEI for on-road mobile sources, "interstate" results were mapped to MOVES restricted roads, while "non-interstate" were mapped to unrestricted.

HPMS (or state-submitted) total VMT was considered the "gold standard" which the long-haul factions would subdivide into long (and hence short) haul VMT. VMT is entered into MOVES separately for single unit and combination trucks, so ERG's objective was to develop

separate long-haul fractions for single-unit and combination trucks. The challenge with this is that the FAF dataset only reports estimates of total long-haul mileage, without distinction by truck type. As an initial step for developing the updated long-haul fractions, ERG estimated long-haul VMT separately for combination and single-unit trucks by multiplying total FAF long-haul VMT by truck allocation factors reported in the FAF documentation. According to the documentation, these allocation factors were developed from the 2002 Vehicle In-Use Survey (VIUS 2002) to assist in apportioning long-haul commodity flow demand to available truck capacity.¹² For long-haul trips (defined in VIUS and MOVES as trips over 200 miles from home base), the single unit truck allocation for long-haul trips was 10.3 percent, with the rest being comprised of combination trucks (this is comparable to the current MOVES default allocation of long-haul VMT to single unit trucks of 11.3 percent, though not surprising because the MOVES defaults were also derived from VIUS 2002). Based on the single unit allocation factor, ERG split the total FAF long-haul VMT estimates into combination and single-unit categories using factors of 0.897 and 0.103, respectively.

The method for developing long-haul fractions relied on combining long-haul VMT allocations from the FAF with combination and single unit truck VMT allocations of from HPMS. The common point of the FAF and HPMS datasets is that both estimate total single unit +combination truck VMT. This becomes the point of reference for the two datasets; FAF can provide the ratio of long-haul VMT to total single unit+combination VMT, while HPMS can provide the ratio of combination and single unit VMT (separately) to the combined total. The long-haul fractions were then derived from these ratios. This approach provides a way for the inconsistency in analysis year of the datasets (2007 vs. 2011) to be addressed, and to extract long-haul allocations from FAF based on internally consistent comparisons.

The level of aggregation at which to calculate these ratios was defined to retain as much of the regional FAF data as possible, while not putting too much weight on extreme values that appeared at the county level. This was determined by comparing the ratio of long-haul:total VMT from FAF (long-haul ratio), to the ratio of single unit +combination truck : total VMT from the 2011 HPMS data (single+combination ratio). Instances where the FAF long-haul ratio exceeded single unit+combination ratio were not considered valid, because it meant FAF was assigning more long-haul VMT than the HPMS data suggested was possible. These comparisons were performed at varying levels of regional aggregation (county, state, census subregions and major census region) and urban/rural split (six and two categories based on population) to find a level of aggregation where the FAF long-haul ratios were all less than the HPMS single+combination ratios. Figure 15 shows a comparison of these ratios by county, showing the invalid condition in many counties where FAF long-haul ratio exceeded HPMS single+combination ratio. Aggregation into 54 regions (6 urban/rural splits by 9 census

subregions) largely corrects this trend, showing all but 1 region with long haul ratio less than single+combination truck ratio (Figure 16).

Figure 15. HPMS Single+Combo Ratio vs. FAF Long-Haul Ratio, by County

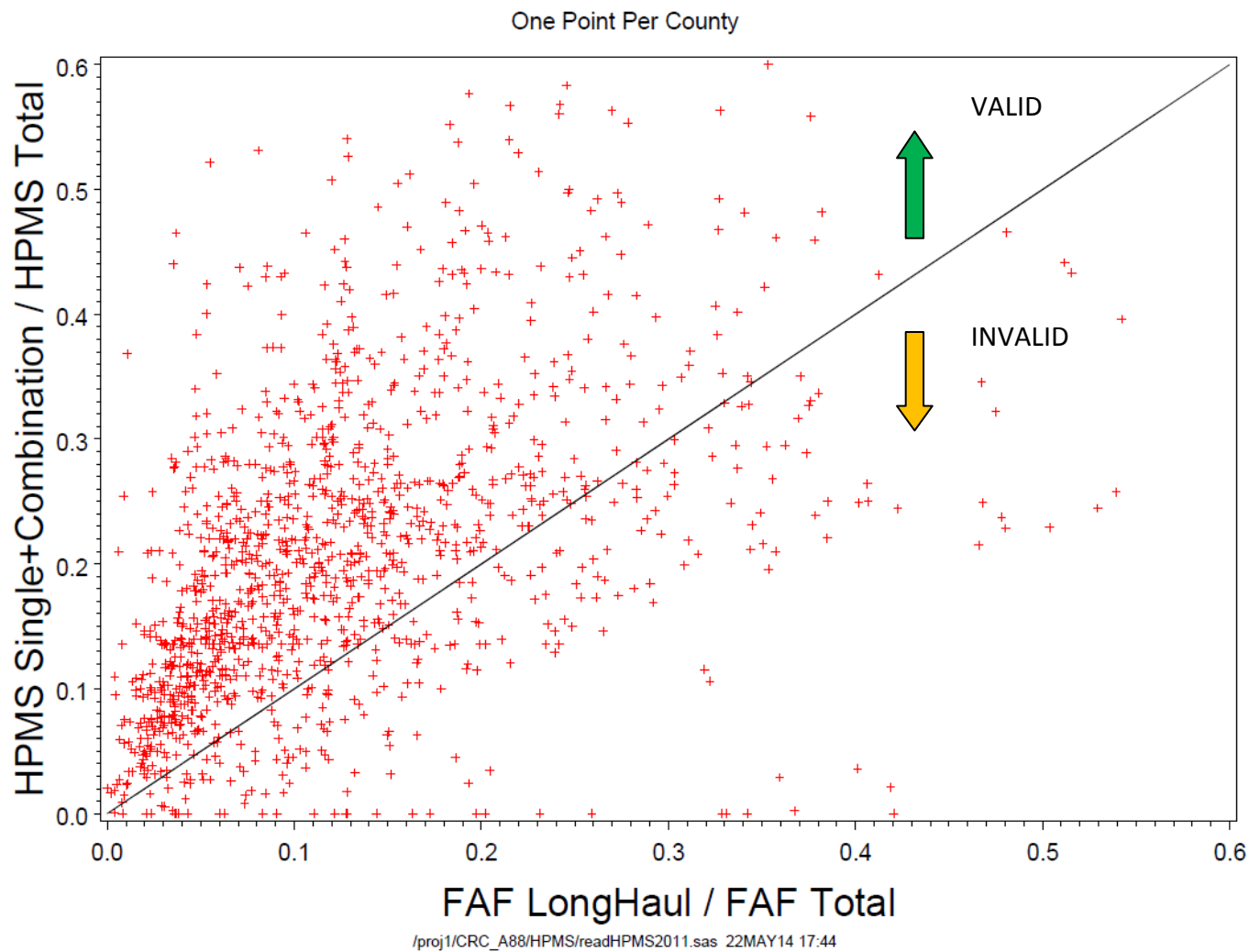
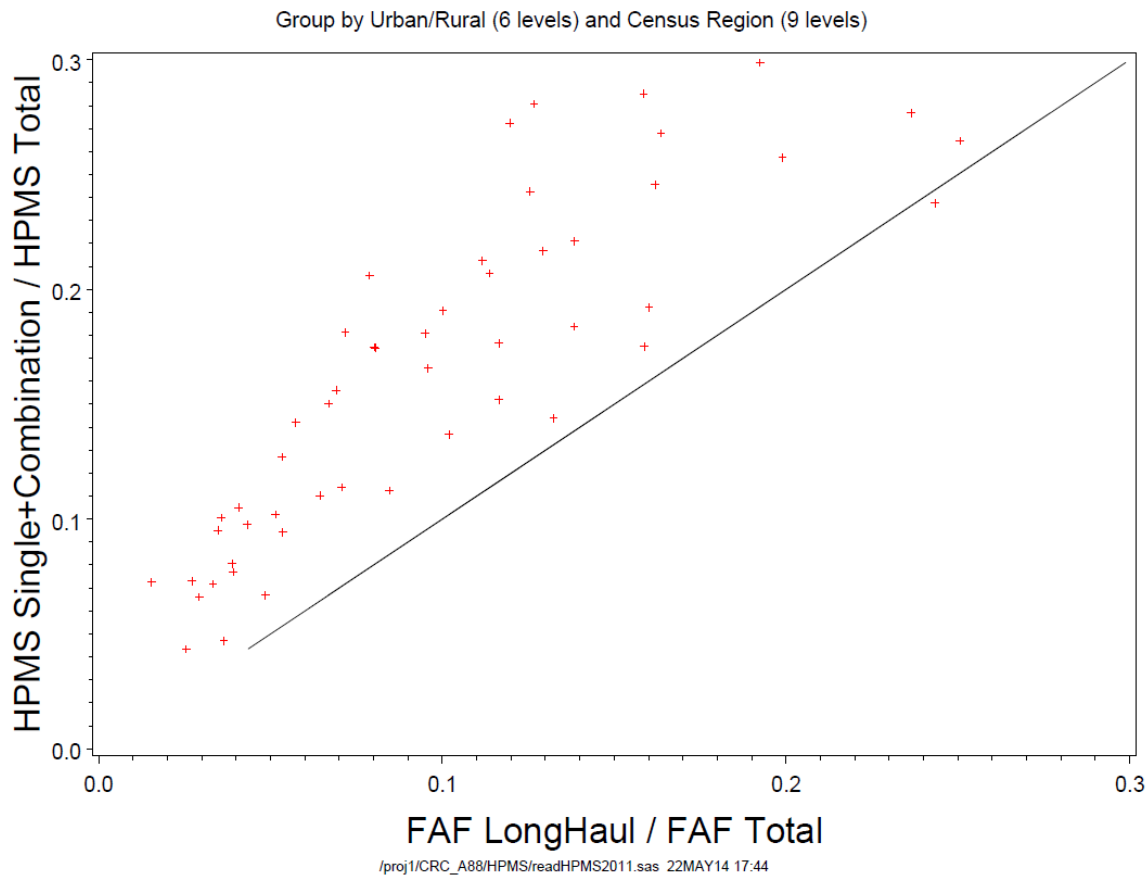


Figure 16. HPMS Single+Combo Ratio vs. FAF Long-Haul Ratio, 54 Regions



Once it was established that aggregation into 54 regions produced a reasonable set of FAF long haul ratios, statistical analysis was conducted to determine the statistical importance of region, urban/rural and roadtype (interstate or non-interstate). The purpose of this was to determine a method for further reduction of the number of regions, while retaining the importance of the FAF dataset. This analysis assumed that overall the FAF numbers are unbiased, i.e. correct, but on a county-by-county basis the FAF numbers (as well as the HPMS numbers) have error. The average trend through the data indicated that for the nation overall, 58 percent of the HPMS large truck VMT is long haul. How that 58 percent might be affected by the 6 levels of urban/rural and the 9 census regions was then assessed. Splitting up the counties by the 6 urban/rural categories resulted in a statistically significant trend with a high F-value (indicates signal-to-noise) of 146 for the regression model, with an increasing long-haul fraction from the most urban (code 1, according to the classification developed by the CDC) to most rural (code 6). For urban codes 1 through 6, the ratio of FAF long-haul VMT to HPMS single+combination VMT was 45, 46, 55, 54, 61 and 65 percent, respectively. That suggests that in the heavily urban counties, the long haul VMT is a smaller fraction of truck VMT than in heavily rural counties, and that some differentiation by urban and rural is important.

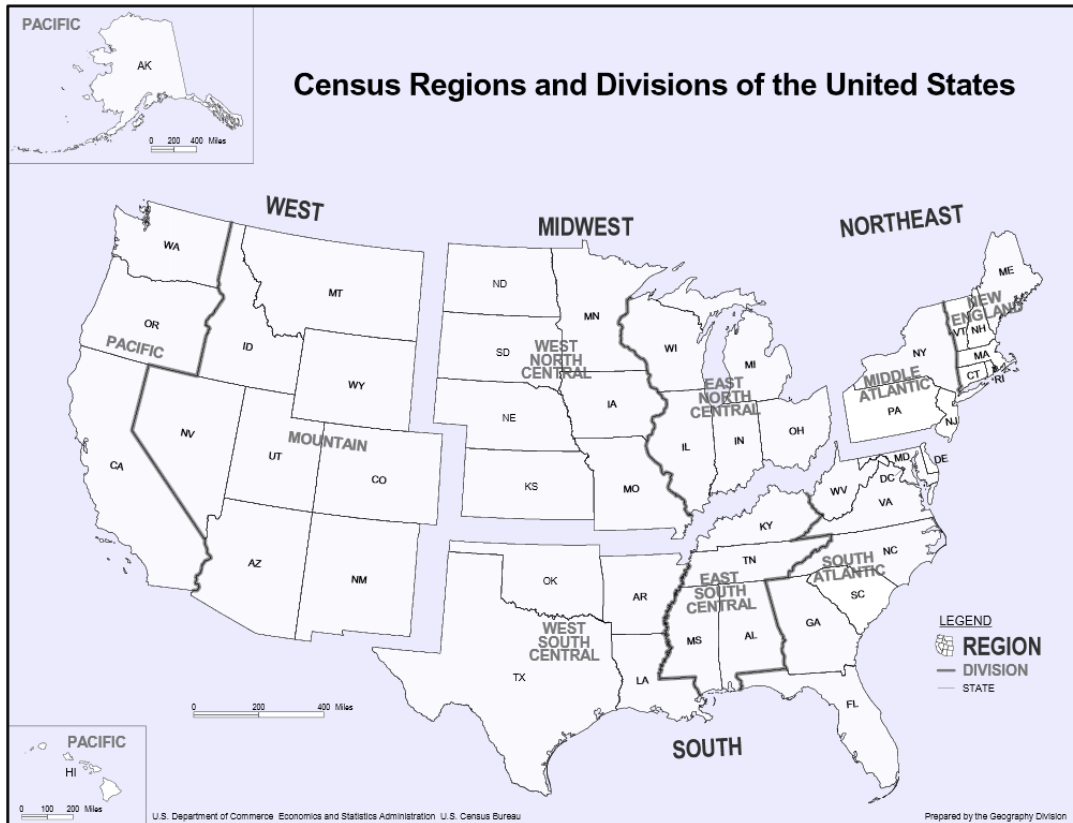
The next step in the analysis focused on 9 census subregions, which produced a statistically significant trend with a high F-value (indicates signal-to-noise) of 115 for the regression model:

- MiddleAtlantic: ratio of FAF long-haul to HPMS single+combination VMT = 94%
- Pacific, 69%
- Mountain, 71%
- WestNorthCentral, 71%
- NewEngland, 52%
- EastNorthCentral, 49%
- SouthAtlantic, 50%
- EastSouthCentral, 42%
- WestSouthCentral, 48%

This analysis suggested a variety in long-haul VMT fraction by region, though there could be confounding between urban/rural areas and census subregions. The analysis found significant differences in interstate and non-interstate as well, which is plausible given the focus of long-haul traffic on interstates.

Although the analysis showed significant trends across 6 urban/rural codes, and across the 9 census subregions, analyzing all of the 54 categories resulting in a model very susceptible to noise (low model F-value) and probable overfitting. This led to further reduction of categories to 16 groupings, covering each combination of: major census region (Midwest, Northeast, South and West, Figure 17), interstate/non-interstate (translated to restricted/unrestricted to match MOVES road types), and urban/rural.

Figure 17. U.S. Census Regions



Long-haul fractions for combination and single unit trucks were then calculated for each of the 16 groups as follows: 1) Estimate the ratio of long-haul VMT to total truck VMT (single+combination) from the FAF data, separately for combination and single unit trucks; 2) Estimate the ratio of combination truck VMT and single unit truck VMT to total single+combination VMT from 2011 HPMS; and 3) Estimate long-haul fraction by dividing the results of steps 1 and 2. The resulting long-haul fractions for combination and single unit trucks are shown in Figures 18 and 19, for each of the 16 groupings. For both combination and single-unit trucks, differences by region, roadtype and urban/rural are shown, bounding the static MOVES default fractions. In general, long-haul fraction is higher on rural vs. urban and interstate vs. non-interstate, which are expected trends. For some regions, the long-haul fractions are quite high (up to 90 percent for combination and 50 percent for single unit) on rural restricted roads. These ratios constitute the final deliverable for long-haul truck VMT for A-88; they were delivered to CRC on July 25, 2014.

Figure 18. Long Haul Fractions for Combination Trucks

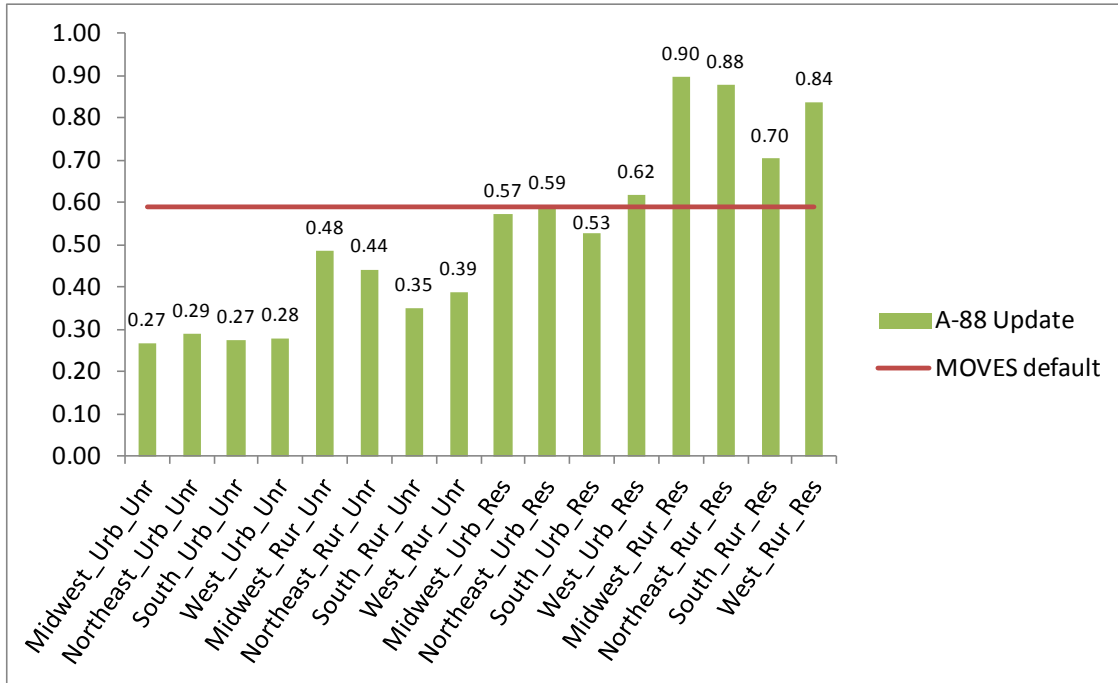
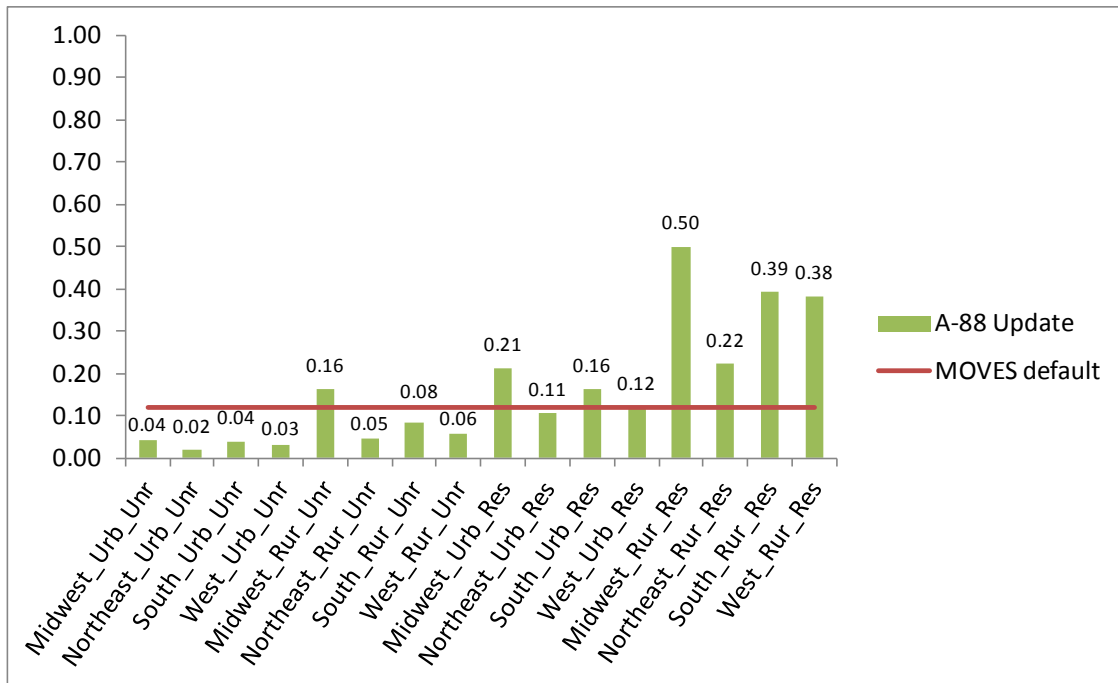


Figure 19. Long-Haul Fractions for Single Unit Trucks



6.0 CONCLUSIONS

CRC sponsored the A-88 project to help improve MOVES inputs for the 2011 NEI. Guided by the results of a preceding A-84 project, ERG identified the most promising MOVES inputs for improvement, and performed a detailed review of candidate data sources for age distribution, population, long-haul truck VMT, start activity and truck extended idling. From this detailed evaluation, ERG centered on passenger car and light truck age distributions and populations and long-haul truck VMT allocations, and developed improved defaults to be applied at the local level. The updated age distributions were based on registration database purchased from IHS, Inc. for each county in the U.S., intended to replace the single average national defaults currently used by MOVES. The age distributions showed an average age range of 4 to 16 years for cars and trucks vs. MOVES national default of 9 years. The updated vehicle population estimates for each U.S. county were developed from the same IHS data. Long-haul truck VMT allocations were derived from the 2007 Freight Analysis Framework, producing unique allocations by region of the country, urban/rural and interstate/non-interstate, and are intended to replace the uniform long-haul allocations currently used in MOVES. The updated long-haul fractions for combination trucks varied by region of the country, road type and urban/rural area, ranging from around 30 percent on urban unrestricted roads, to up to 90 percent for some rural restricted roads, in comparison to a static MOVES default of 59 percent. In conjunction with emission sensitivity results published as part of the A-84 project, the influence on emissions from updating to these new estimates are expected to be significant.

Other findings associated with MOVES inputs were made that model users should consider for future improvements, though not ultimately pursued under A-88. For heavy-duty truck idling, ERG concluded that the commercially available database Truck Stops Plus provides the most comprehensive and detailed database for the analysis. The database contains over 7,300 trucks stops and includes all major chain truck stops, as well as independent truck stops. These data were deemed useful in determining the relative amount of idling at any given location, and were delivered to CRC as part of the deliverables for A-88. For vehicle start activity, an analysis of National Household Travel Survey (NHTS) data indicated that there is a statistically significant observable effect of trips/vehicle/day by geographic region and urban/rural area. Future work could continue investigation of methods to improve heavy-duty idle and vehicle start activity, as well as the potential for emerging vehicle telematics to data to improve activity and trip pattern estimates used in the NEI and local emission inventory development. The MOVES framework was developed to allow a great deal of customization in input data, and data sources that can be used to take advantage of this feature are becoming more readily available, in large part due to technological advances in activity measurement and spatial positioning.

7.0 ACKNOWLEDGEMENTS

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